RUNNING OUT OF RESOURCES

IEEE
SPECTRUM

MONITORING GLOBAL CLIMATE

JULY 1993 THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

Newslog

MAY 12. Tokyo's **NEC Corp.** and **Toshiba Corp.** said they are joining forces with **MIPS Technologies Inc.,** Mountain View, CA, to develop an advanced microprocessor for next-generation desktop computers. The alliance, whose chip will be based on MIPS' reduced-instruction-set computing (RISC) technology, will compete with five other groups that have rallied around other RISC chips, each hoping to make theirs the world standard.

MAY 12. Apple Computer Inc., Cupertino, CA, said it is developing technology to enable application programs designed for its Macintosh PCs to run unmodified on Unix workstations from Sun Microsystems, Hewlett-Packard, and IBM. Until now, Apple's strategy has been to ensure that Macintosh software runs only on Apple computers.

MAY 13. Researchers from **Hitachi Ltd.'s** European laboratories and **Trinity College,** Dublin, have combined two advanced information-processing technologies—optical computing and neural networking—in an artificial eye that recognizes shapes and patterns in a way that mimics human sight. The optical device can "learn" to recognize and distinguish between two patterns, irrespective of their position and movement. None of today's TV-scanning robot vision systems can do that.

MAY 17. LDDS Communications, Jackson, MS, said it had agreed to merge with **Metromedia Communications Corp.,** East Rutherford, NJ, and **Resurgens Communications Corp.,** Atlanta, GA, to create what would be the fourth-largest U.S. long-distance phone carrier. The new company, to be called LDDS-Metro Communications Inc., would have annual revenues of over US $1.5 billion.

MAY 17. Digital Equipment Corp., Maynard, MA, said it is working with **LANCity Corp.,** Andover, MA, on technology for high-speed multimedia data networking over cable television lines, in competition with local telephone companies. The networks, which could connect sites up to 43 km apart, are to use the Ethernet standard and transmit data at 10 Mb/s—about seven times the capacity of most T-1 data lines.

MAY 17. Time Warner Inc., New York City, and **U S West Inc.,** Englewood, CO, said that U S West will invest $2.5 billion in a 25 percent stake in Time Warner's cable and entertainment operations. The companies are to build an interactive network carrying video, data, and voice services on Time Warner cable-TV systems, reaching seven million subscribers. The pact marks the first time a Bell Operating Company has invested in programming that could be carried over the phone network.

MAY 17. Xerox Corp., Stanford, CT, said it had combined a computer and a television receiver in a flat panel the size of a pad of paper to create video screens with photographic clarity. The displays are made from amorphous silicon, measure 33 cm diagonally, and have 6.3 million pixels.

MAY 19. Westinghouse Electric Co., Pittsburgh, said it had clinched two contracts worth up to $400 million to supply technology, equipment, and services to the partially completed Temelin nuclear power station in the **Czech Republic.**

MAY 22. The **Internet global computer network** carried its first digital TV movie, *Wax: Or the Discovery of Television Among the Bees.* Technicians at a film production studio in Manhattan played it on a videocassette recorder (VCR), fed it into a computer, then fed the digitized result into the Internet. Engineers viewing *Wax* on their workstations called the picture acceptable, even though it had only half the resolution of a normal TV image, and was aired at the rate of two frames a second.

MAY 24. The three top groups competing to develop next-generation television technology in the United States said they had agreed on a **single high-definition TV (HDTV) approach.** The move prevents disputes and litigation, which could have delayed the introduction of HDTV for years. The alliance hopes to develop a working model within nine months.

MAY 28. The **Nuclear Regulatory Commission,** Rockville, MD, said it had warned the operators of 34 nuclear boiling-water reactors designed by **General Electric Co.,** Fairfield, CT, that gas bubbles tend to block the pipes in their water-level measurement systems, causing false readings during routine shutdowns that could lead to undetected leaks. The commission told the utilities to take action within 15 days to improve water-level monitoring.

MAY 31. HSST Corp., a Tokyo-based company affiliated with Japan Airlines Co., said it had agreed with **Grumman Corp.,** Bethpage, NY, to jointly produce high-speed, magnetic-levitation trains in the United States. HSST will provide funds and technology, and Grumman will handle production. One possibility is 100–200-km/h trains on a 20-km route between Kennedy and La Guardia airports in New York City.

JUNE 2. British Telecommunications PLC announced that it would buy one-fifth of **MCI Communications Corp.,** Washington, DC, for $4.5 billion and form an alliance to provide global networks for multinational corporations. MCI will sell services in the Americas and the Caribbean, while British Telecom will handle Europe, Asia, and the Pacific Rim.

JUNE 3. Tele-Communications Inc., Englewood, CO, and **Time Warner Inc.,** New York City, said they would form a joint venture to invest in developing compatible hardware and software, so that users of their rival interactive networks could communicate. The aim is to eliminate the kind of incompatibility problems that bedevilled the development of VCRs.

JUNE 4. Researchers at **Pennsylvania State University,** University Park, said they had turned plastic into crystalline diamond by arranging the carbon atoms in a polymer and cooking it at kitchen-oven temperatures. The new mix could help chip makers replace the silicon in densely packed microelectronic circuits with diamond, a far better heat sink.

JUNE 9. Microsoft Corp., Redmond, WA, said its new software architecture, called Microsoft At Work, will grant users easy access to all information, regardless of its origin or format, and will let them manage a range of office communications devices that today are incompatible. Microsoft said its architecture is supported by over 60 companies in office automation, communications, and computers. The first new machines, probably facsimiles, will start appearing by year-end.

Preview:
JULY 17. The space shuttle **Discovery** is to be launched from the Kennedy Space Center, Cape Canaveral, FL, and deploy the **Advanced Communications Technology Satellite.** The satellite, which is to operate for four years, is to conduct over 60 experiments in such technologies as multiple-hopping spot beams, on-board high-speed digital baseband processing and switching, and adaptive rain-fade compensation techniques that could prevent storms from interrupting satellite communications.

COORDINATOR: Sally Cahur

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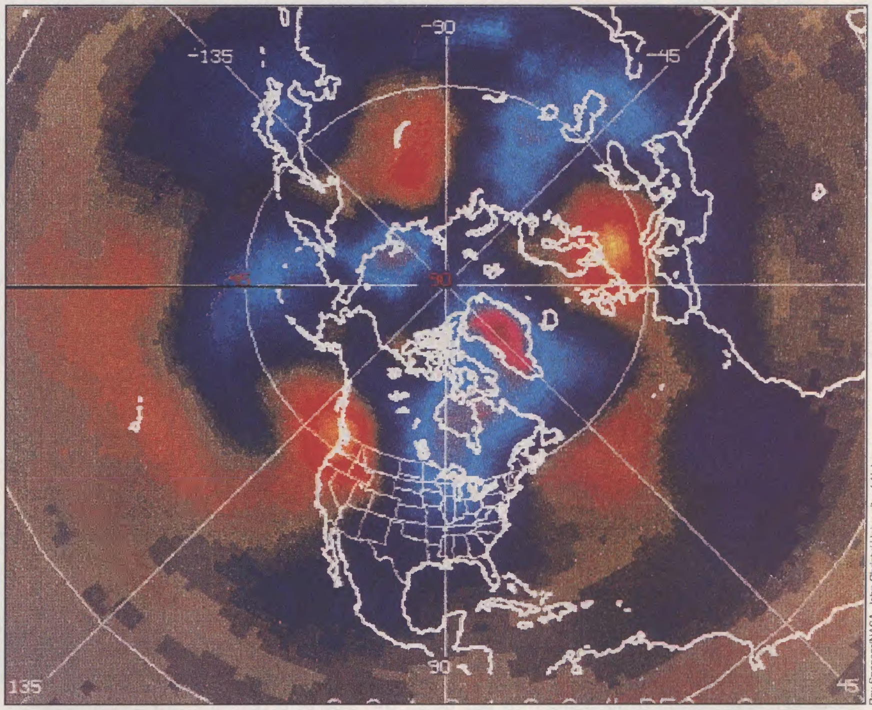
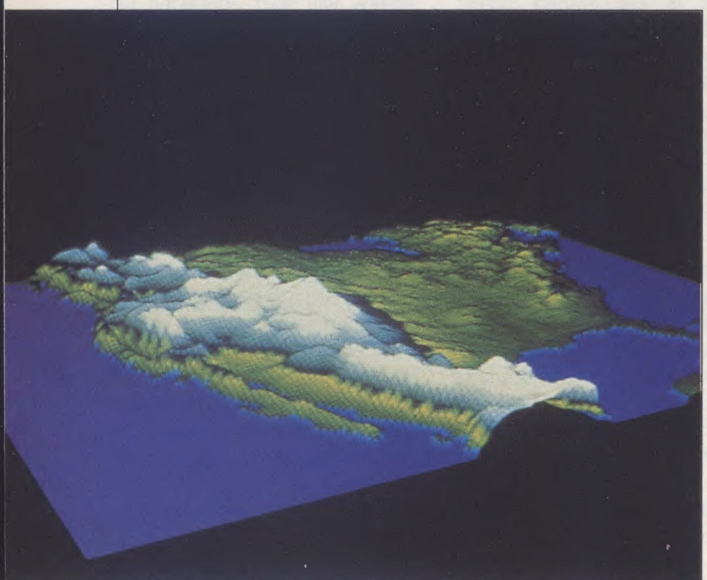
IEEE SPECTRUM



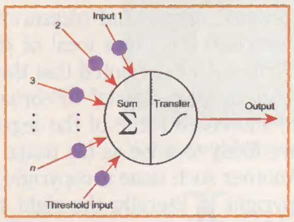
Roy Spencer/NASA, John Christy/ University of Alabama


National Center for Atmospheric Research/University Corp. for Atmospheric Research/NSF

COMPUTERS

By DAN HAMMERSTROM

Neural networks have emerged as a powerful tool for recognizing patterns in

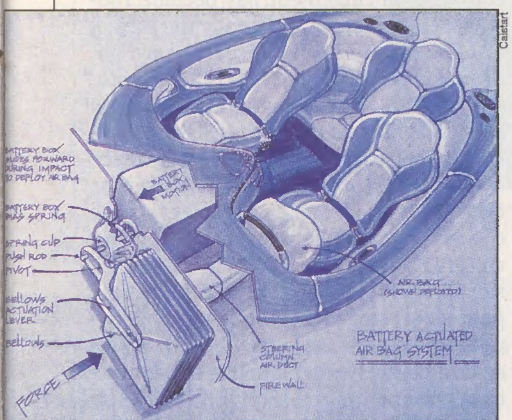


data. This second of two articles deals with the networks' strengths and weaknesses and determining when to use them in a particular application.

CAREERS

By DAVID LYNCH

Attempting to kill two problems (air pollution and unemployment) in one go, this nonprofit organization hopes to turn



Calstart

California into an important source of components for electric—and other—vehicles. This airbag system is actuated by the movement of an electric vehicle's battery in a collision. Other Calstart developments include highly efficient climate controls and a vehicle navigation system.

Cover: Particulates sent into the atmosphere by the Pinatubo volcanic eruption and other sources caused sunsets of rare vibrance, which were photographed by the crew of the space shuttle Columbia in October 1992. This technique of studying atmospheric pollutants by looking along a tangent to the atmosphere will be exploited in advanced satellite instruments to be launched in the next decade. See p. 20.
Credit: National Aeronautics and Space Administration.

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Forum

The limits of encryption

The article "Wiretapping and cryptography" [March, pp. 16–17] and the ensuing responses [May, p. 8] are interesting. For nonmilitary purposes, however, the entire subject may be overemphasized. First consider the regulation of encryption of data over domestic commercial phone lines. Today, there are numerous standards-based and proprietary modem and data formats. Is some government agency going to test and limit everyone to sets of formats that government agencies can process? Where is the break between encryption and efficient channel coding?

How about languages? Will it be illegal to use Navaho dialects or some other language that is used by a particular ethnic group on the commercial phone system because it is not understood by government monitors? What if some group wanted to use a book of coded expressions or a one-time pad to communicate over the phone system? I believe our Constitution and Bill of Rights permit freedom of expression in any language or data form.

(I once worked with an engineer whose family spoke only Latvian at home. Whenever he called his wife from certain government facilities or secure contractor facilities and spoke in Latvian, the call would be disconnected. We used to joke that Latvian sounded like Russian, but perhaps someone was monitoring the phone who did not speak Latvian.)

My second observation is related to the Federal Bureau of Investigation's actions to change the implementation of Signaling System 7 to aid in their wiretapping activities. I am puzzled that no one has commented that these features apply only to trunks and central office switching systems.

Perhaps the FBI does not tap individual analog phone lines, but taps main communications trunks. I would think that with a valid, court-approved wiretap order, the phone companies could take advantage of the new digital signaling features, and digitally distribute the call directly to a phone of the FBI's choice with no loading effects to indicate that the call had been bridged. Or perhaps the FBI requests court approval only after scanning the phone trunks for conversations of interest.

Do we really want our taxes spent to limit our access to technology so that our government has an easier time monitoring our communications? Somehow, I think we might be overlooking the real reason the United States is different from most other countries. Our government is based on individual freedoms and the right to privacy, not efficient government surveillance.

David W. Horner
Silver Spring, MD

Trade Center blast

The Faults & Failures article describing the aftermath of the bombing of the World Trade Center [May, pp. 83–84] failed to mention New York Telephone Co. As area operations manager for New York Telephone, I want to state for the record that *telephone lines were working after the blast.* These lines served as critical communication links between people trapped on the upper floors and the rescue teams that were trying to get them out.

In addition, *our* fire and smoke detection systems were operational and were monitored at our Building Operations Control Center. Shortly after the blast, our (supply) fans automatically shut down in an effort to reduce the smoke penetration at our World Trade Center facility. Fortunately for us, our people were located on the lower levels of the World Trade Center, which made it that much easier to evacuate them.

Steve Babsky
New York City

Warning the user

While reading the article "Computers and epidemiology" [May, pp. 20–26], it occurred to me that it would be relatively simple for an application to include an "antibody": a routine that checks the executable from which it has been loaded and ensures the executable is not infected. Since a program can be given an arbitrary amount of information about itself by the programmer in the form of starting address, size, and checksum or cyclic redundancy code, the problem is no longer one of identifying a virus but of warning a user that an executable is not as it should be. The check would involve little more than a fraction of a second after the program received control.

Since each program could go about these checks in a relatively random way, the problem of writing a computer virus becomes one of back-engineering an application to defeat the built-in checks. So the virus becomes application-specific, which would seriously limit the possibility of an epidemic.

As described above, the approach applies to executables, but this same approach could also work with boot sector viruses, although to a lesser extent. The virus writer would still have to back-engineer a program in order to defeat the checks, but with an installation base of several million, it might be considered worthwhile by a virus enthusiast.

Keith Clifford
Richmond, BC, Canada

Crime and copyright

As grievance officer and treasurer of the San Francisco Bay Area local of the National Writers Union, I noted that the article "Facsimile's false starts" [February, pp. 46–49] addressed some of the legal issues that are likely to arise as fax usage continues. Another such issue is copyright.

Copyright is, literally, the right to copy. Ownership of the copyright to a work entitles the owner to license others to make copies. This license to copy can only be granted by specific arrangements with the owner. In selling an article, for instance, the author grants a magazine the right to make copies of the article. In most cases, authors sell first serial rights, the right to be the first magazine to make copies of the article. The authors keep all other rights to themselves.

With faxes, photocopiers, electronic databases, and similar technologies, it is so easy to make and distribute copies that copyright infringement has become routine. One example was recently the subject of legal action in Federal court (copyright infringement is a Federal crime). Photocopy stores were copying articles from books and magazines, then binding and selling the copies; the articles were selected by university professors as readings for their courses. It was easier for everyone concerned to use the bound copies than for students to read the articles in the university libraries. After the courts held that the photocopy stores were infringing copyright, the stores agreed to abide by a procedure that respects the rights of the copyright owners.

Another example of routine infringement is likely to be the subject of a major class action suit in the near future. The National Writers Union, an affiliate of the United Auto Workers, has begun work on a suit against the major electronic databases and the magazines that provide them with published articles. In the great majority of cases, the magazines do not have the right to allow electronic copies of the articles to be made; the magazines have purchased

specific rights that do not include electronic distribution. The magazines may charge the databases a licensing fee, so the databases may not be guilty of infringement, but the magazines are selling what they do not own, so the databases have, in effect, purchased stolen goods.

Authors, like inventors, do not want to limit the dissemination of information. But they do want an appropriate share of the revenues the dissemination earns. Everyone involved in copying and distributing information—both text and graphics—must respect the rights of the information's creators.

Mike Bradley
San Francisco

Environmental questions

I am writing in response to the article on elimination of hazardous chemicals in the electronics manufacturing industry ["Cleaning up," February, pp. 20–26]. While electronics engineers can be proud of their ingenuity in finding ways to dispense with chlorofluorocarbons (CFCs) in processes such as vapor degreasing, there is evidence that CFCs are not destroying the ozone layer. According to an article in the Dec. 21, 1992, edition of *Automotive News*, the recent total ban on CFCs is based on faulty scientific reasoning.

If CFCs, trichloroethane, and so forth are depleting the ozone layer, we can cope with this problem by imposing an appropriately stringent tax on such chemicals in proportion to their ozone-destroying power. Unlike an outright ban, this approach would provide design and manufacturing engineers with a flexible incentive to use the least harmful substance feasible in any given application, to recycle such chemicals, and to use non-ozone-destroying alternatives when possible.

But at all times we should ask ourselves: are outright bans or high taxes on chemicals necessary to meet legitimate environmental needs? Or are we merely pandering to the emotional needs of neurotic intellectuals? If the latter is true, our efforts to avoid using these chemicals are a waste of our time and the public's money.

Alexander R. Kovnat
West Bloomfield Township, NJ

Time for a degree

The statement in "U.S. education 'doing fine'" [March, p. 66] that only 10 percent of employers responding to a National Society of Professional Engineers survey favored lengthening the engineering study period to five years is incorrect and misleading. Actually, a whopping 36 percent of the respondents favored at least some lengthening of the study period, and the five-year figure was never mentioned in the survey questionnaire.

Ten percent of the respondents favored making the M.S., which generally is scheduled to take even longer than five academic years to earn, the first professional degree. An additional 26 percent favored lengthening the time required for the bachelor's degree (the amount of lengthening was not specified in the questionnaire).

Lawrence Fafarman
Los Angeles

On-line health care?

The long lines one encounters in hospitals and doctors' offices provide telling evidence of the imbalance between supply and demand for medical services. The supply must be increased to control (and drive down) costs through market forces. Here's how: install personal computers in public libraries with expert systems for diagnosing typical ailments and for prescribing appropriate treatments.

Professionals have explored the use of computer-aided diagnoses for over a decade. Their capabilities and limitations should be sufficiently well known to establish the scope of computer-aided diagnostics that could be safely completed by the average adult. The range of diagnoses could be extended by equipping the computer with sensors to noninvasively measure temperature, pulse rate, blood pressure, and, possibly, parameters such as cell counts and cholesterol. With such measurements, it's likely that the reliability of diagnoses could at least equal the typical reliability of diagnoses made by hurried and harried doctors. And such diagnoses could be made available routinely to every citizen, including the homeless, very economically (about US $1 annually per individual).

A properly designed expert system should warn of incompatibilities between various prescription and nonprescription drugs, calculate appropriate dosages for the individual's gender, height, weight, and so on, and identify generic equivalents of brand-name products when they are available. For some types of maladies, standard prescriptions could be issued for generic products, together with directions to contact a physician if specific symptoms appear or if the original problem persists. In other cases, the expert system would document the measurements, present a diagnostic risk profile, and direct the subject to seek professional care immediately. Such a system should encompass routine diagnostic checks to detect symptoms of potentially serious diseases.

How much would it cost? A minimum of about 60 000 systems would be needed to provide universal access (assuming 4000 people use the system for 30 minutes each annually). State-of-the-art PCs and commercial off-the-shelf expert system software could become the platform for a powerful system for only about $5000. Allocating an additional $5000 each for sensors would bring the national cost to $600 million—plus the cost of preparing a standard set of questions and diagnoses.

The tough part: political considerations require that Congress establish a policy that precludes legal action against individuals or agencies that rely on standard diagnoses and prescriptions that have been developed by the national lab, then reviewed and approved by the Surgeon General. If our nation is serious about high-quality, universal health care, we should press Congress to get rid of unnecessary laws and regulations that impede the use of available technology.

Paul T. Burnett
Alamogordo, NM

Ipse dixit

In the review of my book *Mazes for the Mind: Computers and the Unexpected* [April, p. 7], the reviewer states, "Pickover claims that Bertrand Russell published his 20 favorite words . . . ." The reviewer's use of the word "claims" may cast some doubt as to the authenticity of my statement, particularly when considered in the context of the review.

As stated in my book, in 1958 Bertrand Russell was asked to make such a list, and it is published in the first reference book listed in my book's chapter on this subject.

Clifford A. Pickover
Yorktown Heights, NY

Correction

The 12th line of the middle column on p. 23 of the May issue should read as follows: "only if deaths drop below one every three weeks." —*Ed.*

Readers are invited to comment in this department on material previously published in *IEEE Spectrum*; on the policies and operations of the IEEE; and on technical, economic, or social matters of interest to the electrical and electronics engineering profession. Short, concise letters are preferred. The Editor reserves the right to limit debate on controversial issues. Contact: Forum, *IEEE Spectrum*, 345 E. 47th St., New York, N.Y. 10017, U.S.A.; fax, 212-705-7453. The compmail address is ieeespectrum. The computer bulletin board number is 212-705-7308; the password is SPECTRUM. The line parameters are 1200 bits/second, no parity, 8 data bits, and 1 stop bit. For more information, call 212-705-7305 and ask for the Author's Guide.

In 1991, Perrin attempted to drive an EV from California to Vermont. It is an engaging story, and although anyone involved professionally with EVs will find numerous factual and technical errors, these blemishes need not detract from the enjoyment of the book. The opening paragraph of Michael Riezenman's report on EVs—"interesting, exciting, but not to be taken too seriously" [*IEEE Spectrum*, November, 1992, P. 18]—definitely applies here.

The adventure began in 1990, when a student in Perrin's class on environmental studies at Dartmouth College asked, in essence, "If you inveigh against air pollution, why do you drive a fume-belching, gas-guzzling car to the campus?" Perrin could not walk the 20 km to the Hanover, NH, school or bicycle up and down the many steep hills. Ergo, an electric car!

The story occasionally borders on slapstick, including the passages on the circumstances surrounding his purchase of Solo, so named in part because it had solar panels on the roof for charging its batteries. There is a fascinating account of his experiences driving cross-country. After Solo had problems attempting to negotiate the Donner Pass, Perrin abandoned the idea of an all-electric trip. He bought a pickup truck and towing gear and hauled the EV to Peoria, IL. Solo played well thereafter, and Perrin arrived home triumphantly in his politically correct car.

Occasionally on his odyssey from Santa Rosa, CA, to Thetford, VT, Perrin would unhitch Solo, charge it overnight, and tour locally. He had encounters with EV skeptics, buffs, and know-it-alls who, Perrin

"electrical engine" under the hood. One need not check the Society of Automotive Engineers' *Dictionary of Automotive Terms* to learn that it's an electric *motor* and an internal combustion *engine*. Even Webster's makes this distinction.

Perrin properly regrets that Solo does not have regenerative braking, and is thus robbed of extra range by being unable to charge its batteries when going downhill. He eventually learns the unexciting truth, which is that regenerative braking will extend the range of an EV by about 10 percent at best. The main purpose of this feature is actually drive train retardation, for safety and to give the "feel" of a conventional car. No self-respecting manufacturer of EVs would build one today without it.

Many impressions given about EVs in general are incorrect, being based on Perrin's particular EV. The design lacks at least the following: amperage instrumentation, a dc/dc converter, a good state-of-charge indicator, and chargers that will charge both propulsion and auxiliary batteries safely and correctly independently of control settings. At a selling price of US $17 500, the manufacturer could have spent an additional $100 for a shunt (separately excited) motor, with regenerative braking coming almost free. All this indicates that the manufacturers are not "experts on EVs," as Perrin (quite understandably) thought them to be.

Perrin was not told of the utter impossibility of climbing the Donner Pass on less than two full battery charges. The energy stored in a lead-acid battery is barely sufficient to lift itself vertically more than about 610 meters. The Donner Pass involves a climb of more than 1610 meters.

nels have limited utility. ıs under way, they provided percent of Solo's propul- with several days of plen- ould the batteries be fully olar panels alone.

elies on some questionable sources for predictions otes *Newsweek* and *Popular* re worthy publications but ord on EVs.

een similarly ill-served by from auto manufacturers' lepartments. He writes, for M will have the Impact on 5," whereas GM has since n any firm production date

me cute terms that could infatuation with one's own has, after all, written for *The New Yorker*). He prefers to "eat in a slow-food restaurant," for instance.

In a similar vein, he rejects the conclusion of most serious students of EVs: that the only Ultra Low Emission Vehicle that can be produced with today's technologies is the heat-engine/battery-electric hybrid. Perrin dismisses the compromise with an erudite literary-theological quotation from St. Augustine, paraphrased as: "Make me chaste, Lord, but not yet."

Victor Wouk (LM) is the U.S. representative to the International Electrotechnical Commission's Committee on Electric and Hybrid Road Vehicles, a field he has been active in since 1964. He has written, spoken, and testified widely on these vehicles and other topics in transportation. Earlier he founded Beta Electric Corp. and Electronic Energy Conversion Corp., which produced, respectively, high-voltage power supplies and solid-state high-power conditioning equipment. He planned and designed the electric bus system for the residential complex on Roosevelt Island, in the East River between Manhattan and Queens in New York City.

Society and the telephone

David Gabel

Claude S. Fischer tackles an interesting question: how does the introduction of new technology affect our lives? Does it radically alter our social relationships, or is the change marginal?

This question is timely because of the current debate over the information revolution's long-term impact on social and business relations. But the computer's effect is still in its formative stage and the outcome is uncertain.

Fischer's focus is the telephone, and his

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Environmental q

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Clifford A. Pickover
Yorktown Heights, NY

Correction

The 12th line of the middle column on p. 23 of the May issue should read as follows: "only if deaths drop below one every three weeks." —*Ed.*

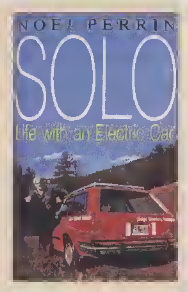
Readers are invited to comment in this department on material previously published in *IEEE Spectrum*; on the policies and operations of the IEEE; and on technical, economic, or social matters of interest to the electrical and electronics engineering profession. Short, concise letters are preferred. The Editor reserves the right to limit debate on controversial issues. Contact: Forum, *IEEE Spectrum*, 345 E. 47th St., New York, N.Y. 10017, U.S.A.; fax, 212-705-7453. The compmail address is ieeespectrum. The computer bulletin board number is 212-705-7308; the password is SPECTRUM. The line parameters are 1200 bits/second, no parity, 8 data bits, and 1 stop bit. For more information, call 212-705-7305 and ask for the Author's Guide.

Books

Voyage of an electric vehicle
Victor Wouk

Fifty book reviewers can't be wrong—and they're not. Critics in august newspapers and scientifically oriented magazines have been justifiably enthusiastic about these "adventures of Noel Perrin and his electric car" (hereinafter referred to as an electric vehicle, and by the affectionate shorthand EV).

Solo: Life With an Electric Car.
Perrin, Noel, W. W. Norton, New York, 1992, 191 pp., $18.95.



In 1991, Perrin attempted to drive an EV from California to Vermont. It is an engaging story, and although anyone involved professionally with EVs will find numerous factual and technical errors, these blemishes need not detract from the enjoyment of the book. The opening paragraph of Michael Riezenman's report on EVs—"interesting, exciting, but not to be taken too seriously" [*IEEE Spectrum*, November, 1992, P. 18]—definitely applies here.

The adventure began in 1990, when a student in Perrin's class on environmental studies at Dartmouth College asked, in essence, "If you inveigh against air pollution, why do you drive a fume-belching, gas-guzzling car to the campus?" Perrin could not walk the 20 km to the Hanover, NH, school or bicycle up and down the many steep hills. Ergo, an electric car!

The story occasionally borders on slapstick, including the passages on the circumstances surrounding his purchase of Solo, so named in part because it had solar panels on the roof for charging its batteries. There is a fascinating account of his experiences driving cross-country. After Solo had problems attempting to negotiate the Donner Pass, Perrin abandoned the idea of an all-electric trip. He bought a pickup truck and towing gear and hauled the EV to Peoria, IL. Solo played well thereafter, and Perrin arrived home triumphantly in his politically correct car.

Occasionally on his odyssey from Santa Rosa, CA, to Thetford, VT, Perrin would unhitch Solo, charge it overnight, and tour locally. He had encounters with EV skeptics, buffs, and know-it-alls who, Perrin seems not to realize, know little. Finding an outlet for plugging in the battery charger could be an adventure. His descriptions of truck stops rival those of post–World War II motels in Vladimir Nabokov's *Lolita*.

My basic uneasiness is that Perrin implies, misleadingly, that what happened to him would happen to anybody who bought an electric car today. This need not be so. A second criticism is that the book was not vetted by an expert—someone who understands both the theory and practical design of EVs—to get rid of the technical errors. For example, Perrin states that lead-acid batteries, when rested for 10–15 minutes, "recover" somewhat because they "*re*polarize." Perrin undoubtedly misheard someone who was saying "*de*polarize."

I admit I became somewhat biased early on in the book, where Perrin refers to the "electrical engine" under the hood. One need not check the Society of Automotive Engineers' *Dictionary of Automotive Terms* to learn that it's an electric *motor* and an internal combustion *engine*. Even Webster's makes this distinction.

Perrin properly regrets that Solo does not have regenerative braking, and is thus robbed of extra range by being unable to charge its batteries when going downhill. He eventually learns the unexciting truth, which is that regenerative braking will extend the range of an EV by about 10 percent at best. The main purpose of this feature is actually drive train retardation, for safety and to give the "feel" of a conventional car. No self-respecting manufacturer of EVs would build one today without it.

Many impressions given about EVs in general are incorrect, being based on Perrin's particular EV. The design lacks at least the following: amperage instrumentation, a dc/dc converter, a good state-of-charge indicator, and chargers that will charge both propulsion and auxiliary batteries safely and correctly independently of control settings. At a selling price of US $17 500, the manufacturer could have spent an additional $100 for a shunt (separately excited) motor, with regenerative braking coming almost free. All this indicates that the manufacturers are not "experts on EVs," as Perrin (quite understandably) thought them to be.

Perrin was not told of the utter impossibility of climbing the Donner Pass on less than two full battery charges. The energy stored in a lead-acid battery is barely sufficient to lift itself vertically more than about 610 meters. The Donner Pass involves a climb of more than 1610 meters.

The solar panels have limited utility. While the car was under way, they provided no more than 5 percent of Solo's propulsion power. Only with several days of plentiful sunshine could the batteries be fully charged by the solar panels alone.

The author relies on some questionable authorities. As sources for predictions about EVs, he quotes *Newsweek* and *Popular Science*, which are worthy publications but hardly the last word on EVs.

Perrin has been similarly ill-served by upbeat reports from auto manufacturers' public relations departments. He writes, for example, that "GM will have the Impact on the roads by 1995," whereas GM has since backed away from any firm production date whatsoever.

There are some cute terms that could be attributed to infatuation with one's own wittiness (Perrin has, after all, written for *The New Yorker*). He prefers to "eat in a slow-food restaurant," for instance.

In a similar vein, he rejects the conclusion of most serious students of EVs: that the only Ultra Low Emission Vehicle that can be produced with today's technologies is the heat-engine/battery-electric hybrid. Perrin dismisses the compromise with an erudite literary-theological quotation from St. Augustine, paraphrased as: "Make me chaste, Lord, but not yet."

Victor Wouk (LM) is the U.S. representative to the International Electrotechnical Commission's Committee on Electric and Hybrid Road Vehicles, a field he has been active in since 1964. He has written, spoken, and testified widely on these vehicles and other topics in transportation. Earlier he founded Beta Electric Corp. and Electronic Energy Conversion Corp., which produced, respectively, high-voltage power supplies and solid-state high-power conditioning equipment. He planned and designed the electric bus system for the residential complex on Roosevelt Island, in the East River between Manhattan and Queens in New York City.

Society and the telephone
David Gabel

Claude S. Fischer tackles an interesting question: how does the introduction of new technology affect our lives? Does it radically alter our social relationships, or is the change marginal?

This question is timely because of the current debate over the information revolution's long-term impact on social and business relations. But the computer's effect is still in its formative stage and the outcome is uncertain.

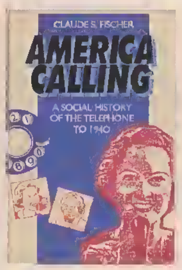
Fischer's focus is the telephone, and his

Books

research provides an interestingly different model for evaluating the social effects of technological change. He argues that it is not terribly productive to ask what the impact of new technology is. He believes that this type of language frames the issue wrongly because it "implies that human actions are impelled by external forces when they are really the outcomes of actors making purposeful choices under constraints."

In order to understand what happens, he believes that we must first ask "who adopted the [new technology], when, where, how, and why; [to] what ends; and [for] what uses."

America Calling: A Social History of the Telephone to 1940.
Fischer, Claude S., University of California Press, Berkeley, 1992, 424 pp., $25.



He is meticulous in his analysis. His book explores how the telephone affected social relations from the time the service was born, in the 1870s, until the start of World War II. He studies the issues from many angles; he has combed the archives of regional and national telephone companies, trade journals, and local newspapers, and has interviewed some of the telephone users who were alive at the start of the 20th century. He combines this qualitative data with a thorough statistical examination of the available data sets on the ways the telephone was used before 1940.

Fischer concludes that the telephone, as is the case with many new technologies, has impinged only marginally on social relations. The telephone became part of daily life, but without dramatically altering it. According to Fischer, the remarkable invention was primarily used to bolster existing social patterns, although exceptions can be found.

One of the most impressive aspects of the author's research is his disinclination to persuade his readers that there is a "best" model for understanding how new technologies can alter human behavior. Throughout, he compares the social impacts of the telephone, the automobile, and television, and argues that the other two products have affected social patterns more profoundly.

As a sociologist, Fischer has accepted the difficult task of identifying and quantifying changes in social relations. While some activities can be measured—for example, the number of people who are called on the telephone and the frequency with which they are contacted—it is difficult to gauge the nature and quality of the conversations held.

For example, in the course of a telephone call, neither person involved can "read" the other's face; without such visual cues, there may be a reluctance to explore certain topics. Therefore, a telephone conversation may be quite different in nature from one conducted face-to-face. Fischer's research is a model for how historians and sociologists can try to gauge changes in human interaction.

His narrative also illustrates how different the eventual uses and social impact of new technology often are from what is initially envisioned by social commentators or the technology's inventors. For example, Fischer points out that for approximately the first 30 years of telephony, the dominant firm in the industry, the American Telephone & Telegraph Co., envisioned the technology being used for business, and even discouraged customers from using it for social reasons. Having worked earlier for Western Union, the early management

(Continued on p. 16)

MULTISYNC COLOR MONITORS: THE MILLION-SELLING TREND-SETTERS.

Sales of NEC's MultiSync™ color monitors for personal computers have soared past the one million mark. MultiSync scored a smash hit when introduced in 1985 because it was a leading-edge monitor that offered auto-sync compatibility with various types of PCs and graphics boards. MultiSync was the first monitor to standardize the Super VGA video mode.

MultiSync continues to set the standard for PC monitors. Today's enhanced MultiSync displays are designed for graphics-intensive windowing environments. With flatter, squarer screens, they offer brighter, sharper, more accurate images.

MultiSync monitors in the FG Series also feature a unique color calibration system. The AccuColor™ control system allows users to adjust on-screen colors at will. The red, green and blue guns can be separately controlled in precise digital steps.

Advanced digital controls also automatically size and center screen images for preset and custom graphics modes.

Ergonomic features range from an improved cabinet design to a new anti-static, low-reflection screen. Reduced Magnetic Field™ technology lowers ELF and VLF emissions to meet Sweden's strict MPR II guidelines.

NEC's new MultiSync monitors are available in 15, 17 and 21-inch models.

NUMBER 150

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Reporters and aid workers have a new high-tech communications tool. NEC's compact INMARSAT-M phone provides reliable telephone and facsimile services to and from anywhere in the world.

The portable voice terminal for the INMARSAT-M satellite communication service consists of a transceiver, flat antenna, handset and rechargeable battery, all integrated in a briefcase-size unit.

It takes just minutes to set up the phone, using a visual indicator to align the antenna with the satellite. The terminal connects with GIII facsimile machines.

The new INMARSAT-M phone is about half the size, weight and cost of conventional INMARSAT-A terminals. It will become an indispensable tool for professionals working in remote areas where communications are unreliable or non-existent.

Circle No. 6 for Inmarsat-M Phone

NEW ZEALAND LAUNCHES AIN SYSTEM.

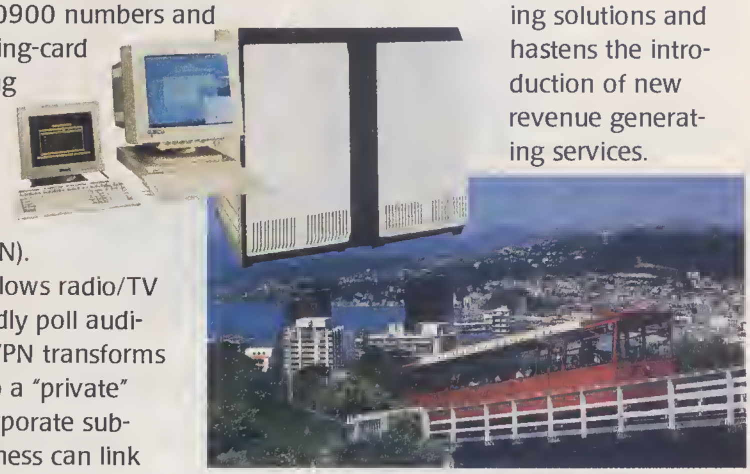
Telecom Corporation of New Zealand Limited has inaugurated an Advanced Intelligent Network (AIN), offering advanced services to subscribers across the country.

The system already provides enhanced 0800/0900 numbers and automated calling-card services. Coming attractions include televoting and virtual private networking (VPN).

Televoting allows radio/TV stations to rapidly poll audience opinion. VPN transforms public lines into a "private" network for corporate subscribers. A business can link branches nationwide. Employees call simply by dialing extensions.

New Zealand's AIN integrates NEAX61 switches installed in 296 exchange offices. AIN runs on NEAX61 application service processors using Stratus fault-tolerant computers and its software developed by NEC.

AIN demonstrates the scope and scale of systems that can be implemented with NEC's Customized Networking Platform (CNP). CNP provides optimum networking solutions and hastens the introduction of new revenue generating services.



VR4400 64-BIT RISC PROCESSOR.

NEC has introduced the industry's most powerful processor for workstations and servers. The new VR4400, an upgrade of the world's first 64-bit RISC microprocessor, runs at 150MHz internally and performs over 100 SPECMark.

Enhanced features include extra on-chip memory capacity. The VR4400 reduces power demands with singlechip configuration and 3.3V or 5V operation.

An easy design-in, the VR4400 is pin- and software-compatible with the VR4000. The open architecture supports both UNIX SVR4 and Windows NT.

NEC offers three versions: the standard VR4400 PC, the VR4400 SC with a secondary cache controller and the VR4400 MC for multiprocessor systems.

NEC

Books

(Continued from p. 12)

of AT&T was used to the telegraph being used almost exclusively by the business community, and saw the telephone as a similar tool. Only slowly did it realize that the social use of the telephone was a new and profitable market.

The desire of customers to socialize over the telephone illustrates Fischer's more general point, that people adopt a new technology to meet their own needs, that it is not the technology that determines the change.

This is a first-rate, scholarly book. The research is refreshing, because the author does not believe that a single theory can explain the evolution of an industry or social relations. His study illustrates the complexity of the process of social change—a process that can only be understood through thorough and thoughtful analysis of the sort he provides.

David Gabel is associate professor of economics at Queens College, in New York City. His primary research areas are the history of the telephone industry and its current cost and pricing structure. He has written widely on such subjects as the pricing of telecommunications services, regulation, investment in regulated industries, and AT&T's strategic response to competition.

COORDINATOR: Glenn Zorpette

Recent books

Digital Hardware Testing: Transistor-Level Fault Modeling and Testing. *Rajsuman, Rochit*, Artech House, Norwood, MA, 1992, 425 pp., $78.

Building A Better Mousetrap: A Programmer's Guide to the Mouse. *Donovan, Jeffrey S.*, Osborne/McGraw-Hill, New York, 1992, 525 pp., $29.95.

Computer-Aided Analysis and Design of Switch-Mode Power Supplies. *Lee, Yim-Shu*, Marcel Dekker, New York, 1993, 648 pp., $125.

ORACLE 7: The Complete Reference. *Koch, George*, and *Muller, Robert*, McGraw-Hill, New York, 1992, 1000 pp., $34.95.

VSATs, Very Small Aperture Terminals. *Everett, John L.*, Peter Peregrinus/IEE, Piscataway, NJ, 1992, 543 pp., $119.

Word 5.1 Companion. *Cobb, Gena B., et al.*, Microsoft Press, Redmond, WA, 1993, 720 pp., $29.95.

VSAM: Concepts, Programming, Design, 2nd edition. *Ranade, Jay*, and *Ranade, Hirday*, McGraw-Hill, New York, 1992, 456 pp., $44.95.

Design of Logic Systems, 2nd edition. *Lewin, Douglas*, and *Protheroe, David*, Van Nostrand Reinhold, New York, 1992, 702 pp., $40.95.

Database Tuning: A Principled Approach. *Shasha, Dennis E.*, Prentice Hall, Englewood Cliffs, NJ, 1992, 239 pp., $29.

The System Engineer's Handbook. Ed. *Black, John*, Academic Press, New York, 1992, 300 pp., $139.

Nuclear Power: Technical and Institutional Options for the Future. *National Academy Press*, Washington, DC, 1992, 215 pp., $27.

Principles of Medical Imaging. *Shung, K. Kirk, et al.*, Academic Press, San Diego, CA, 1992, 289 pp., $74.95.

Computer Engineering Handbook. *Chen, C.H.*, McGraw-Hill, New York, 1992, 595 pp., $79.50.

Program notes

Windows API: private or public property

Sun Microsystems Inc. is campaigning to move control of the Windows application programming interface (API) from Microsoft Corp. to an international standards organization. Success would place the API for Microsoft Windows, the fastest-growing operating system in history, in the public domain.

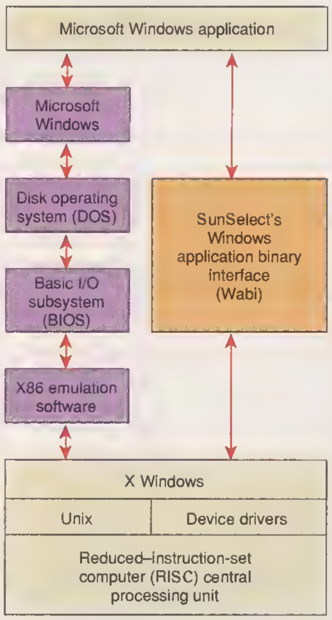
Many software developers prefer a public domain API because it cannot contain undocumented functions available only to certain application programmers, who thereby gain an unfair edge in the marketplace. Support for an independent definition of the Microsoft Windows API was announced in May by some of Microsoft's largest application and operating-system competitors, including Borland International, WordPerfect, and Unix Systems Laboratories. The new Public Windows Interface (PWI), as it is called, was developed by SunSelect, a subsidiary of Sun Microsystems.

Summarizing the position of PWI proponents, Scott McNeeley, chief executive officer of Sun Microsystems, said, "Changes to the Windows API affect [all software developers] and [all end-] users. Something that significant should be debated in a public, open forum." Sun has offered PWI to any organization willing to openly maintain it (just as the X Consortium maintains the X Window System standards).

Sun argues that because PWI was developed from public specifications for the Windows interface, it could be controlled by an international standards organization without infringing on Microsoft's copyrights or patents. Microsoft spokesman Collins Hemmingway said, "We haven't seen [PWI] so we have no position on it, but we will defend our property."

Shortly before the PWI announcement, Microsoft licensed its Windows technology to Insignia Solutions Inc., the Mountain View, CA, developer of Windows emulation packages for Unix. Further, it is looking for other Unix vendors who want to license the same technology, which may reduce the demand for a public Windows API.

The first product based on PWI is SunSelect's Windows application binary interface (Wabi). Wabi translates Microsoft Windows function calls into X Window function calls. Thus Windows applications can run more efficiently on Unix operating systems that support X Windows [see figure]. SunSelect is licensing Wabi to Unix vendors who wish to produce Windows-ready Unix systems. *For PWI or Wabi, contact: SunSelect, 2 Elizabeth Dr., Chelmsford, MA 01824-4195; 508-442-2300;* or **circle 100.** *For running Windows applications on Unix, contact: Insignia Solutions Inc., 526 Clyde Ave., Mountain View, CA; 415-694-7600; or* **circle 101.**



SunSelect's Windows binary application interface (Wabi), unlike previous systems for running applications for Windows in other environments, is a translator, not an emulator. By directly converting a Windows application's binary code into its X Windows equivalent, Wabi avoids time-consuming Windows, DOS, BIOS, and X86 emulations and speeds up the application.

Another look at rows and columns

As operating systems and personal computers have become more powerful, spreadsheet designers have begun to explore data storage formats that simplify linking data stored in different regions of the spreadsheet.

In taking this approach, Lotus Development Corp. has created an algorithm that represents the data in a multidimensional format. Instead of the traditional up-down, left-right relationships between pieces of data, Lotus defined 12 possible relationships, letting users create new relationships within data without breaking the old ones.

Since displaying multidimensional relationships is difficult, Lotus has added to that technology a second: dynamic viewing. Dynamic viewing displays any relationships of interest to the user in the traditional columnar format.

Lotus has incorporated this multidimensional technology and dynamic viewing in Improv. It was developed on OS/2, first sold for the NeXT computer, and is now available for Microsoft Windows. As recent Improv sales figures demonstrate, users are interested in developing connections between pieces of data on different parts of a spreadsheet: Improv was on several best-seller lists in April and May. *Contact: Lotus Development Corp., 55 Cambridge Parkway, Cambridge, MA 02142; 617-577-8500; or* **circle 102.**

The beginning of the end, maybe

Few tools have simplified the primary job of the programmer: writing source code. The only computer-aided software engineering (CASE) tools to have done so are screen generation programs, which produce the source code required to create graphical user interfaces from simple inputs.

Now Microsoft Corp. has introduced so-called wizards into the Visual C++ programming environment. A spinoff from technology developed to speed the creation of macro-instructions in Access database and Excel spreadsheet applications, a wizard uses dialog boxes to extract from the programmer the information it needs to automatically generate the code.

Wizards may be visualized as the software equivalent of an IC standard cell library—essentially shortcuts that save programmers' time by coding commonly used functions. Visual C++ contains two kinds of wizards. AppWizards automate generation of application frameworks. A ClassWizard connects the user interface elements to classes supplied with Visual C++, turning the framework into code.

While wizards do not reduce the amount of custom code, which is what makes an individual application unique, they simplify building nuts-and-bolts code. Standard cell libraries did not eliminate the need for custom ICs, and wizards will not eliminate the need for custom coding. Even so, they do mark the end of programming as it has been practiced for the past 20 years. *Contact: Microsoft Corp., 1 Microsoft Way, Redmond, WA 98052-6399; 206-882-8811, or* **circle 103.**

CONTRIBUTOR: John R. Hines is silicon sensors engineer at Honeywell Inc.'s Micro Switch Division, Richardson, TX.
COORDINATOR: Richard Comerford

Calendar

Meetings, Conferences, and Conventions

JULY

World Congress on Neural Networks (C, NN); July 11–15; Oregon Convention Center, Portland; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

International Vacuum Microelectronics Conference (ED); July 12–15; Hotel Viking, Newport, RI; Charles A. Spindt, SRI International, 333 Ravenswood Ave., Menlo Park, CA 94025; 415-859-2993.

International Semiconductor Manufacturing Science Symposium (ED); July 18–21; San Francisco Marriott, San Francisco; Eileen Vierra, Semi, 805 East Middlefield Rd., Mountain View, CA 94043; 415-940-6988; fax, 415-967-5375.

Power Engineering Society Summer Meeting (PE); July 18–22; Hotel Vancouver & Hyatt Regency, Vancouver, BC, Canada; B.C. Prior, B.C. Hydro & Power Authority, 1611 Southpoint Dr., Podium A01, Burnaby, BC V3N 4X8, Canada; 604-528-1600, ext. 2736.

Summer Topical Meetings: Optical Microwave Interactions (LEO, MTT), July 19–21; **Visible Semiconductor Lasers** (LEO), July 21–23; **Hybrid Optoelectronic Integration and Packaging** (CHMT, LEO), July 26–28; **Impact of Fiber Nonlinearities on Lightwave Systems** (LEO), July 26–28; **Gigabit Networks** (COM, LEO), July 28–30; Fess Parker Red Lion Resort, Santa Barbara, CA; Cathy Goldsmith, IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3894; fax, 908-562-1571.

International Microprocess Conference (ED); July 19–22; International Conference Center Hiroshima, Hiroshima, Japan; Susumu Namba, Business Center, 5-16-9 Honkomagome, Bunkyo-ku, Tokyo 113, Japan; (81+3) 5814 5800.

11th International Conference on Conduction and Breakdown in Dielectric Liquids–ICDL '93 (DEI); July 19–23; ABB Research Center, Baden, Switzerland; Peter Biller, ABB Management AG, Dattwil, CH5405 Baden, Switzerland; (41+56) 76 8277.

Sixth International Workshop on Computer-Aided Software Engineering (C); July 19–23; Institute of Systems Science, National University of Singapore, Kent Ridge, Singapore; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

30th IEEE Nuclear and Space Radiation Effects Conference (NPS); July 19–23; Snowbird Ski and Summer Resort, Snowbird, UT; James R. Schwank, Sandia National Laboratories, Department 1332, Box 5800, Albuquerque, NM 87185; 505-844-8376.

Second International Symposium on High Performance Distributed Computing (C); July 21–23; Cavanaugh's Inn, Spokane, WA; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

Regional Control Conference (CS); July 23–24; New Jersey Institute of Technology, Newark; Timothy N. Chang, Department of Electrical and Computer Engineering, Newark, NJ 07402; 201-596-3519.

Joint Technical Conference on Circuits/Systems Computers and Communications—JTC-CSCC '93 (CAS); July 26–28; Nara Women's University, Nara, Japan; Kenji Onaga, Department of Information Engineering, University of Ryukyus, Nishihara, Okinawa 903-01, Japan; (81+98) 895 2221; fax, (81+98) 895 2688.

International Conference on Intelligent Robots and Systems—IROS '93 (IE, RA); July 26–30; Pacific Convention Plaza, Yokohama, Japan; Kyoichi Tatsuno, Energy Science and Technology Laboratory, R&D Center, Toshiba Corp., 4-1 Ukishimo-cho, Kawasaki-ku, Kawasaki 210, Japan; (81+44) 288 8076; fax, (81+44) 288 8213.

IEEE members attend more than 5000 IEEE professional meetings, conferences, and conventions held throughout the world each year. For more information on any meeting in this guide, write or call the listed meeting contact. Information is also available from: Conference Services Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 80055; 908-562-3878; submit conferences for listing to: Ramona Foster, *IEEE Spectrum*, 345 E. 47th St., New York, NY 10017; 212-705-7305.

For additional information on hotels, conference centers, and travel services, see the Reader Service Card.

AUGUST

Cornell Conference on Advanced Concepts in High-Speed Semiconductor Devices and Circuits (ED); Aug. 2–4; Cornell University, Ithaca, NY; Pallab Bhattacharya, Department of Electrical Engineering, University of Michigan, 1301 Beal Ave., Ann Arbor, MI 48109-2122; 313-763-6678; fax, 313-747-1781.

International Microwave Conference/Brazil (MTT); Aug. 2–5; Convention Center Reboucas, São Paulo, Brazil; Flavio Pillon Richards, Sociedade Brasileira de Microondas, Instituto Maua de Tecnologia, Estrada das Lagrimas, 2035, 09580-900, São Caetano Do Sul, São Paulo, Brazil; (55+11) 743 8988.

Hot Interconnects Symposium (C); Aug. 5–7; Stanford University, Palo Alto, CA; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013.

Workshop on Hierarchical Test Generation (C); Aug. 8–11; Virginia Polytechnic Institute and State University, Blackburg, VA; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

Fifth International Conference on Human-Computer Interaction (COM, SMC); Aug. 8–13; Hilton at Walt Disney World Village, Orlando, FL; Gavriel Salvendy, HCI International '93, 1287 Grissom Hall, Purdue University, West Lafayette, IN 47907-1287; 317-494-5426; fax, 317-494-0874; e-mail, salvendy@ecn.purdue.edu.

Intersociety Energy Conversion Engineering Conference (ED); Aug. 8–13; Hyatt Regency Hotel, Atlanta, GA; Diane Ruddy, American Chemical Society, 1155 16th St., N.W., Washington, DC 20036; 202-872-4600.

International Workshop on Memory Testing (C); Aug. 9–10; Marriott Hotel, Santa Clara, CA; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

International Symposium on Electromagnetic Compatibility—EMC '93 (EMC); Aug. 9–13; Grand Kempinski Hotel, Dallas; Joe Stanfield, SEI, 9226 Markville Dr., Dallas, TX 75243; 214-690-9881.

36th Midwest Symposium on Circuits and Systems (CAS, CS, et al.); Aug. 14–17; Westin Hotel Renaissance Center, Detroit, MI; Michael P. Polis, Department of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; 313-577-3920.

International Geoscience and Remote Sensing Symposium (GRS); Aug. 18–21; Kogakula University, Tokyo; Mikio Takagi, Institute of Industrial Science, University of Tokyo, 7-22-1 Roppongi Minato-ku, Tokyo 106, Japan; (81+3) 3479 0289; fax, (81+3) 3402 6226.

Eighth International Symposium on Intelligent Control (CS); Aug. 25–27; Knickerbocker Hotel, Chicago; Panos J. Antsaklis, Department of Electrical Engineering, University of Notre Dame, Notre Dame, IN 46556; 219-613-5792.

International Conference on the Applications of Diamond Films and Related Materials (ED); Aug. 25–27; Sonic City Hall, Omiya Saitama, Japan; ADC '93 Secretariat, International Communications Inc., Kasho Building 2-14-9 Nihombashi, Chuo-ku, Tokyo 103, Japan; fax, (81+03) 3273 2445.

Solid State Circuits and Technology Workshop on Low-Power Electronics (SSC); Aug. 25–27; Biltmore Hotel, Phoenix, AZ; Ran-Hong Yan, AT&T Bell Laboratories, Holmdel, NJ 07733; 908-949-7695; fax,

(Continued on p. 18D)

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Calendar

(Continued from p. 18A)

908-949-6010; or Bob Nielsen, Eastman Kodak Co., Eastman Kodak Research Laboratory, Rochester, NY 14650-2024.

International Conference on Solid-State Devices and Materials (ED); Aug. 29–Sept. 1; Nippon Convention Center, Chiba City, Japan; SS DM Secretariat, c/o Business Center for Academic Societies Japan, Honkomagome 5-16-9, Bunkyo-ku, Tokyo 113, Japan; (81+3) 5814 5800.

International Symposium on Gallium Arsenide and Related Compounds (ED); Aug. 29–Sept. 2; Karlsbau Congress Center, Freiburg, Germany; Hans J. Boehnel, Fraunhofer Institut für Angewandte Festkorperphysik, Tullastrasse 72, W-7800 Freiburg, Germany.

SEPTEMBER

Fourth European Conference on Electron and Optical Beam Testing of Electronic Devices (R); Sept. 1–3; Swiss Federal Institute of Technology (ETH), Zurich; Mauro Ciappo, Reliability Laboratory, ETH-Zentrum, CH-8092 Zurich, Switzerland; (41+1) 256 2436; fax, (41+1) 251 2172.

Athens Power Tech—Planning, Operation and Control in Today's Electric Power Systems (PE, Greek Section); Sept. 5–7; Athens Concert Hall, Greece; B.C. Papadias, National Technical University of Athens, Electric Energy Systems Laboratory, Patission St. 42, Athens 106 82, Greece; (30+1) 360 0551 or 361 1983.

Computers in Cardiology Conference (EMB); Sept. 5–8; Imperial College of Science, Technology, and Medicine, London; Richard Kitney, Centre for Biological and Medical Studies, Imperial College, Exhibition Road, London SW7 2BT, United Kingdom; (44+71) 225 8525.

Workshop on Neural Networks for Signal Processing (SP); Sept. 6–9; Maritime Institute of Technology and Graduate Studies, Linthicum Heights, MD; Gary Kuhn, Siemens Corporate Research, 755 College Rd., East, Princeton, NJ 08540; or Barbara Yoon, ARPA-IST, Wilson Boulevard, Washington, DC 20002.

Fifth Conference on Optical Hybrid Access Networks (COM, Region 7); Sept. 7–9; Four Seasons Hotel, Montreal; Raymond Quintal, 700 de La Gauchetière West, 18W2, Montreal, PQ, H3B 4L1, Canada; 514-870-3060; fax, 514-870-9560.

Fifth International Conference on Simulation of Semiconductor Devices and Processes (ED); Sept. 7–9; Technical University of Vienna, Austria; Siegfried Selberherr, Institute of Microelectronics, Gusshausstrasse 27-29/E360, A-1040 Vienna, Austria; (43+1) 58801 3855; fax, (43+1) 5059224.

Fourth International Symposium on Personal, Indoor and Mobile Radio Communications—PIMRC '93 (COM); Sept. 9–11; Pacifico Yokohama Convention Center, Yokohama, Japan; Shuzo Kato, NTT Radio Communications Systems Laboratories, 1-2356 Take, Yokosuka, 238-03 Japan; (81+46) 859 3470; fax, (81+46) 859 8022.

Sixth International Conference on Transmission and Distribution Construction and Live-Line Maintenance (PE); Sept. 12–17; Riviera Hotel and Casino, Las Vegas, NV; Ed Cromer, Nevada Power, MS90A, Box 230, Las Vegas, NV 89151; 702-657-4001; fax, 702-657-4036.

Magnetic Recording Conference (MAG); Sept. 13–15; University of Minneapolis, MN;

Protect Your Retirement: Support Portable Pensions

The IEEE's United States Activities unit, IEEE-USA, is backing Federal legislation to increase the adequacy and efficiency of the private pension system. H.R. 1874, *The Pension Portability Improvement Act*, would:

- **Reduce vesting requirements** from five to three years.
- **Improve pension portability** by permitting vested employees to transfer earned benefits from one retirement savings plan to another.
- **Preserve pension assets** through direct transfers of vested benefits to individual retirement accounts (IRAs) or other portable pension plans.

WHAT YOU CAN DO

U.S. IEEE members can help by writing to their Representatives in Washington. Urge them to enact portability improvement legislation during the current Congress. Tell them how important it is to reduce vesting requirements, guarantee transferability of pension benefits, and promote pension preservation.

Additional information on the legislation and how you can communicate your support to lawmakers is available from IEEE-USA's Vin O'Neill (v.oneill@ieee.org).

IEEE United States Activities
1828 L Street, N.W., Suite 1202
Washington, D.C. 20036-5104
(202) 785-0017 (Voice)
(202) 785-0835 (Fax)

Calendar

Mardi Geredes, IIST, Santa Clara University, Santa Clara, CA 95053; 408-554-6853.

Petroleum and Chemical Industry Technical Conference—PCIC '93 (IA, St. Louis/C); Sept. 13–15; Clarion Hotel, St. Louis, MO; Harold B. Dygert, Clark, Richardson & Biskup, 655 Craig Rd., Suite 240, St. Louis, MS 63141; 314-997-1515.

International Conference on Control and Applications (CS); Sept. 13–16; Le Meridien Vancouver Hotel, Vancouver, BC, Canada; Guy Dumont, Pulp & Paper Center–UBC, 2385 E. Mall, Vancouver, BC V6P 1Z4, Canada; 604-822-8564.

Software Engineering Standards Symposium (C); Sept. 13–17; Hospitality Inn, Brighton, United Kingdom; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013.

Virtual Reality Annual International Symposium (NN); Sept. 18–23; Sheraton Hotel, Seattle, WA; Thomas Caudell, Boeing Computer Services, Boeing Building 33-07, MS 7L-22, 2760 160 Ave., S.E., Bellevue, WA 98008; 206-865-3763.

International Symposium on Semiconductor Manufacturing (ED); Sept. 20–21; Austin Marriott Hotel at the Capital, Austin, TX; Steven Leeke, Texas Instruments Inc., MS 457, Box 655012, Dallas, TX 75265; 214-995-2249; fax, 214-995-1724.

Autotestcon '93 (AES et al.); Sept. 20–23; San Antonio Convention Center, San Antonio, TX; Robert E. Noble, 2500 Fallbrook, TX 78232; 512-491-0311.

15th International Congress on Instrumentation in Aerospace Simulation Facilities—ICIASF '93 (AES); Sept. 20–23; Institute at Saint-Louis, Saint-Louis Cedex, France; Hans J. Pfeifer, French-German Research Institute (ISL), 5 rue de l'Industrie, B.P. 34, F68301 Saint Louis Cedex, France; (33+89) 69 51 60; fax, (33+89) 69 51 62.

Second Network Management and Control Workshop (C); Sept. 21–23; Westchester Marriott Hotel, Tarrytown, NY; Judy Keller, IEEE Communications Society, 345 East 47th St., New York, NY 10017; 212-705-7365; fax, 212-705-7865.

43rd Annual IEEE Broadcast Symposium (BT); Sept. 22–23; Hotel Washington, Washington, DC; Edmund Williams, PBS, Engineering Department, 1320 Braddock Place, Alexandria, VA 22314; 703-739-5172.

15th Annual Electrical Overstress/Electrostatic Discharge Symposium—EOS/ESD (CHMT); Sept. 26–27; Buena Vista Palace, Lake Buena Vista, FL; EOS/ESD Association Inc., 200 Liberty Plaza, Rome, NY 13440; 315-339-6937.

Holm Conference on Electrical Contacts (CHMT); Sept. 26–29; Pittsburgh Vista, Pittsburgh; Holm Conference Registrar, IEEE Technical Activities, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3895; fax, 908-562-1571.

Second International Workshop on Emerging Technologies and Factory Automation—ETFA '93 (IE et al.); Sept. 27–29; Palm Cove Resort, North Queensland, Australia; Alfred C. Weaver, Department of Computer Science, Thornton Hall, University of Virginia, Charlottesville, VA 22903; 804-982-2201.

International Symposium on Subscriber Loops and Services (COM); Sept. 27–Oct. 1; Vancouver Trade & Convention Center, Vancouver, BC, Canada; Shahid Hussain, BC Tel, 2-4535 Canada Way, Burnaby, BC, V5G 1J9, Canada; 604-654-7420.

Reflections

Riding the wave

I pause on my bike ride alongside the surfing beach. Like large black bugs, the surfers bob in a jagged line, inexplicably clustered in one small area of the formless ocean. The setting sun glistens on the backs of their wet suits as they are lifted for a moment by a passing wave. Although it looks like a perfectly good wave to me, none of them moves or stops concentrating on the featureless, watery expanse before them. Up and down they rise and fall, watching and conserving their energy for the big wave that will eventually arise.

My own patience is quickly exhausted, and I turn to leave when suddenly most of the surfers begin paddling strongly toward the shore. They know more than I do about the ocean, for the black bugs are now metamorphosed into human surfers balancing precariously in the curl of a large wave. Of course, "large" is relative—this is New Jersey, and the dirty ocean is quickly bestrewn with arms, legs, and boards. Only one black bug still bobs out in the distance, betting on an even bigger wave yet to come.

It occurs to me that most of us act in a similar manner with respect to technology. There are a lot of us electrosurfers out there, bobbing up and down, watching the tremors of technology and preparing to paddle when we believe a big wave might be forming. It is a difficult sport that only a few of us have mastered. Choose the wrong wave, and you are unceremoniously dumped after an ungainly and abortive run. Start paddling too late and the wave passes you by, as your more perceptive associates sweep triumphantly toward shore.

However, the prizes in electrosurfing are not necessarily for the longest or best ride. Perhaps what counts most is how many other surfers choose the same wave. Looking ahead at the rippling field of technology is not enough. Good electrosurfers glance frequently to their left and right, watching for signs that their fellow surfers might begin paddling. When the wave crests and most of your friends and competitors are standing on top, you must be there, too. If you are left at sea, it will be fruitless to protest that you are awaiting a bigger wave. If that is your strategy, your wave had better be a lot bigger, and if you cannot persuade many others to join you, no one will even notice your ride.

Not all surfers count equally. When a surfer with a Microsoft or Intel label on her back starts paddling, you have to take special notice. These people seem to make their own waves. Remember, however, your friends who followed the surfer from Wang, and who sank beneath the swell as the little wave died away. Take notice also of the large surfer in the big blue wet suit who seems to be floundering uncertainly. Laugh if you will, but ignore his strokes at your peril.

It used to be that the government had very special surfers. They would point in a direction and declare a wave by definition. "Ada will be the main wave in software," they said. "Gossip will replace TCP/IP for communications protocols." But the waves that followed didn't look so big. Maybe the government is just another surfer now, and perhaps it can't make its own waves. This means that government needs to learn to watch the waves and to sense the winds of the market with the rest of us. It, too, can bob in the ocean and guess where the other surfers will jump—the essential skill of our time.

Gus Sauter

I often marvel at how things actually happen in technology. I used to believe that they came about from great invention—like the great individual ride. The need to read the waves and to predict where they might crest was never in my mind. I remember years ago when one of my associates told me breathlessly about the terrific new microprocessor he had conceived. "Better than Intel," he insisted. Naturally, he wanted blessing and support. I think that I agreed with him that his chip probably was better than Intel's—taking his word for it—but I lamented that it didn't matter. When the other fellow has disappeared with the only wave around, it is pretty futile to start paddling on your own. I occasionally have friends who come up with new computer languages, too. They are always supposed to be better than C or Fortran or whatever—and maybe they are, but they just never start a wave.

There are counter examples, of course. You can't ignore all the waves simply because not many surfers are paddling. I remember first hearing about the RISC processor chip. Neat idea, I thought, but no chance of attracting any surfers. Its later success just goes to show that if a technological wave is big enough, people will come. And sometimes big waves just seem to arise spontaneously from calm. Object-oriented programming stirred restlessly for years. Then a few surfers started paddling in hopes of convincing others that a wave was approaching. Now there are throngs of hopeful surfers standing on their boards. It appears that a real wave is forming; otherwise a lot of them are going to look silly.

Often standards committees try to tell us where the waves will be. "ISDN," they say. Or maybe it is "OSI." "Get on board," they insist. But standards only work when they persuade all the surfers to start paddling, and as someone recently observed, most standards are dead on arrival. You have to do your own assessment of when people will move; that is where today's skill lies. For example, it seems that ATM will be the great new communications wave. I'm out there paddling, and so is everyone to my right and left. Occasionally I look back to see if a wave is actually forming. I think it is, but I've been wrong before. Please join me!

Well, it is time for me to remount my bike and pedal home before dark. I wish I had the skills that I admire in these Atlantic surfers. One thing is for sure: in technology now, the surf is up. What we do with it—when we paddle and how well we ride—that is what separates the winners from the losers.

Robert W. Lucky

Sensing climate change

An international effort to monitor what progress is doing to the planet could be the largest technical undertaking in history

The world's space programs have in a few decades reaped dividends that were scarcely imagined by even the most starry-eyed of science-fiction pioneers. International telecommunications and broadcasting, astounding views of the solar system's outer planets and insights into its origins, more accurate storm warnings, and reconnaissance are but a few of the benefits now widely taken for granted.

What may be the biggest benefit of all is fast approaching. In laboratories, computer centers, and government agencies all over the world, an immense project is taking shape whose goal is determining what industry and technology have done, and are doing, to the global climate and environment. At stake is nothing less than the future quality of life on earth.

With circumstantial evidence mounting that nearly two centuries of industrial-age pollution has indeed begun altering the earth's climate and environment, the need for more conclusive and illuminating evidence has become urgent, to say the least. The affected phenomena include many fundamental to sustaining life, such as the global distribution of arable land, fresh water, and storms, and the type and intensity of radiation reaching the planet's surface.

Appropriately, the effort to monitor and model climatic and environmental change is international, and even seen by some as an evolving model for global cooperation in space. Never before has a space project required nations to cooperate on such a scale.

Electronic and optical technologies of every kind will underpin what will ultimately be a vast orbiting and terrestrial infrastructure for monitoring and modeling the global climate and environment. Sensors will include space-based, airborne, and surface instruments, of both passive and active varieties. They will monitor frequencies ranging from the microwave through the infrared, the visible, and the ultraviolet regions. An exhaustive survey of environmental and climatic remote sensing is impossible in a magazine article, so the focus here will be on a select number of vital scientific questions and the technologies that researchers are counting on to help answer them. For the sake of brevity, the article will also concentrate on satellite-based sensors.

Facilities for processing and storing data will have to cope not only with the unprecedented torrent of data from these sensors, but also with an international community of researchers demanding easy access. A key challenge is enabling them to spot significant trends hidden within these huge data sets. The Mitre Corp.'s Nahum Gershon and Grant Miller describe some of the challenges being encountered in the design of the data-processing facilities for the National Aeronautics and Space Administration's Earth Observing System (EOS), the intergovernmental, many-satellite project that is the planned cornerstone of near-term climate and environmental monitoring efforts. Gershon and Miller's article begins on p. 28.

Such data are also being used to fuel supercomputer models of global climate, some of which look 500 years or more into the future. This is not a new use of supercomputers, but as Senior Editor Tekla S. Perry notes, today's gigaflops machines are only beginning to allow researchers to build models complex enough to detect climate change on a regional level [p. 33].

As might be expected, researchers are latching on to the latest technological advances almost as they occur. Light detection and ranging (lidar) sensors, and others built with compact, integrated microwave electronics, are either being tested or soon will be. New algorithms will be needed to make the data-processing tasks manageable, and

Glenn Zorpette Senior Associate Editor

A cirrus cloud drifting 9–11 km above Coffeyville, KS, was captured by a light detection and ranging (lidar) system operated by the University of Utah. Pointed upward from the ground, the lidar registered small but telling details, such as the uncinus cells, which are the wispy curls on top. These puffs freeze water droplets or haze into ice crystals, which are often borne along by the wind to become the long, thin body of the cirrus cloud. Consisting mostly of reflective ice crystals but subject to phase changes, cirrus clouds play a pivotal role in the earth's radiation budget.

University of Utah, Deptartment of Meteorology

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the latest massively parallel architectures are being eagerly pressed into the modeling effort.

Despite this level of activity and commitment, however, most researchers have few illusions about the ability of a 15-year project to entirely comprehend extremely complex atmospheric processes that have been two centuries in the making, and whose effects will likely persist for centuries more. "EOS is really not a long-term monitoring activity," said George Ohring, chief of the Satellite, Research Laboratory at the National Environmental Satellite, Data and Information Service, Suitland, MD, run by the National Oceanic and Atmospheric Administration (NOAA), Washington, DC.

Rather, as some researchers have optimistically pointed out, EOS is the prototype of future long-term monitoring missions. About halfway through EOS's 15-year span, the world's scientific, technical, and political communities will have to decide what comes next.

SIZABLE INVESTMENT. Already, enthusiasm is high in view of the fact that one of the largest international scientific and technological enterprises in history is literally about to get off the ground. "Over the next decade, there's going to be 50 environmental satellites launched in the world," according to John H. McElroy, dean of engineering at the University of Texas at Arlington. "If each one of them costs \$250 million–\$500 million, including the launch, that is a sizable investment in this business." McElroy is assistant administrator of NOAA and a former deputy director of the National Aeronautics and Space Administration's Goddard Space Flight Center, in Greenbelt, MD.

For the international EOS project, the U.S. budget alone through the year 2000 is \$8 billion. EOS is by far the largest component of NASA's Mission to Planet Earth, which is in turn part of the United States Global Change Research Program.

Much of this activity is being guided, at least indirectly, by a series of priorities established in the autumn of 1991 by a group of EOS interdisciplinary investigators and an intergovernmental panel on climate change. The top priority identified was a broad one encompassing the climatic effects of clouds, water vapor, precipitation, and solar radiation. The last factor is itself somewhat complicated, involving the balance between the solar radiation received by and that reflected from earth and the variability of the radiation reaching the planet.

These phenomena are important for several reasons. Computer models of long-term climate change and greenhouse warming vary by as much as 500 percent, largely because of uncertainties concerning cloud properties. Clouds play a rather complex and poorly understood role in greenhouse warming. On the one hand, at very low altitudes they tend to cool the atmosphere by reflecting radiation back into space. At the same time, higher-altitude clouds add heat to the atmosphere by absorbing thermal energy emitted by the earth's surface.

> A vast orbiting and terrestrial infrastructure is planned, to tackle questions about global climate change

According to Michael D. King, the EOS senior project scientist at NASA, this cooling, or albedo, effect of clouds is large. It may be seven times the warming effect expected from atmospheric carbon dioxide when its concentration rises to double the level prevailing in preindustrial times.

Clouds are also precursors of precipitation, which for many researchers is actually the main concern. "Clearly, the thing that is most worrisome about climate change is whether there are going to be large-scale changes in precipitation patterns," explained Jeff Dozier, professor of geography at the University of California in Santa Barbara and King's predecessor as EOS project scientist at NASA. Furthermore, clouds, water vapor, and precipitation are "the part of the earth's system whose response to increasing carbon dioxide is highly uncertain and very important," he added.

From a preindustrial level of 270 parts per million, atmospheric carbon dioxide has risen to about 350 ppm and should reach 540 ppm by the middle of the next century, many experts believe. So one of the chores routinely imposed on supercomputer models is determining the effects of carbon dioxide concentrations twice as high as those of preindustrial times. Most of these models predict global mean temperature increases as high as 3–5 °C, with steeper rises in the polar regions (other theories predict significantly smaller global rises). But "where they disagree with each other is over the precipitation changes," said Dozier.

The source of much of the precipitation over the continents appears to be evaporation from the continents themselves, he explained, whereas the prevailing view 20 years ago was that most of it, even in the interiors of continents, was evaporation from the oceans. Consequently, Dozier said, "if you warm things up you're likely to dry out the continents, especially in the interiors"—and, possibly, start a downward spiral: less rain means less water to evaporate, meaning less rain, and so on.

Reflecting the primacy of these hydrological concerns, an impressive number and variety of sensors are being developed to estimate precipitation, water vapor, the water content of clouds, and temperature. Among the most interesting and useful of these are a new class of infrared and microwave sensors launched recently or planned for launch in the mid-1990s. Most exploit quirks of the earth's troposphere (the lowest part of the atmosphere, ex-

tending from the earth's surface out to about 11–16 km).

SYMBIOTIC SENSORS. Infrared and microwave remote sensing is actually a form of spectroscopy. Certain bands of radiation interact with various atmospheric molecules in a complex way. The molecules both emit and absorb the radiation, some bands more strongly than others. Thus receivers sensitive to these microwave bands register the atmospheric deeps from above or below and, with the earth's surface and the cold vacuum of space compensated for, pile up a wealth of information about their chemistry and physics.

Together, passive infrared and microwave sensors can measure the temperature and humidity profiles of the atmosphere and the concentrations of a host of trace gases. Infrared sensors, for example, are used to measure much the same quantities as their microwave counterparts, but their spatial resolution is typically better. According to Joel Susskind, chief of the Satellite Data Utilization Office at Goddard's Laboratory for Atmospheres, current infrared temperature sounders can take profiles with at least twice the vertical resolution in the troposphere as that of microwave sounders, whose resolution is typically on the order of 6–8 km.

The microwave systems, however, have the great advantage of penetrating clouds and precipitation, which absorb infrared. This property, exploited in a combined microwave-infrared system, allows researchers to take into account the effects of clouds on infrared observations, and so to make effective use of the higher-resolution infrared in up to 70 percent cloud cover, according to Susskind. Thus microwave and infrared sensors must be combined for all-weather, high-resolution sounding and monitoring.

EMERGING TECHNOLOGIES. Both infrared and microwave systems are benefiting greatly from emerging technologies. The Atmospheric Infra Red Sounder, a high–spectral-resolution unit to be launched in 2000 on a versatile satellite called EOS PM, will have advanced Stirling-cycle mechanical coolers. The satellite's infrared sensors will be based on mercury cadmium telluride detectors, which must be chilled at least to liquid nitrogen temperatures for optimal signal-to-noise ratios. At least one scientific platform, the Upper Atmosphere Research Satellite, already has the coolers, but otherwise they have been used almost exclusively in classified intelligence or military satellites.

Cutting-edge technologies are also transforming microwave remote sensing. For monitoring climate, the main molecules of interest are traditionally those of water and oxygen, and the most important microwave bands are at about 22 and 60 GHz. More recently, however, higher frequencies, above 100 GHz, have been used to spot trace molecules at stratospheric altitudes. This technique, called limb sounding, is important for ongoing efforts to monitor the deterioration of the earth's ozone layer. "This is a really important area with a lot of future," said Michael A. Janssen, manager of the space physics and astrophysics section of the earth and space sciences division at Jet Propulsion Laboratory, in Pasadena, CA.

SENSING WATER. Almost all the atmosphere's components—other than water—are transparent to microwaves at about 22 GHz. So for a sensor looking down from orbit, all received energy in this band can be attributed to either water or the earth's surface. The surface and the liquid water in clouds can be characterized by other frequency bands and factored out (a much easier proposition if the background is the relatively homogeneous ocean surface). What is left is water vapor. In principle, the liquid water can also be estimated with an accuracy that depends on how well certain properties of the clouds and precipitation are known or can be inferred.

As the frequencies are shifted still higher, above 30 GHz, the wavelengths begin to match the diameters of falling raindrops. The received signal scatters with a strong and predictable dependence on frequency, from which precipitation rates, if not extreme, can be roughly estimated [see photo, p. 26]. The technique does not work well with snow or hail.

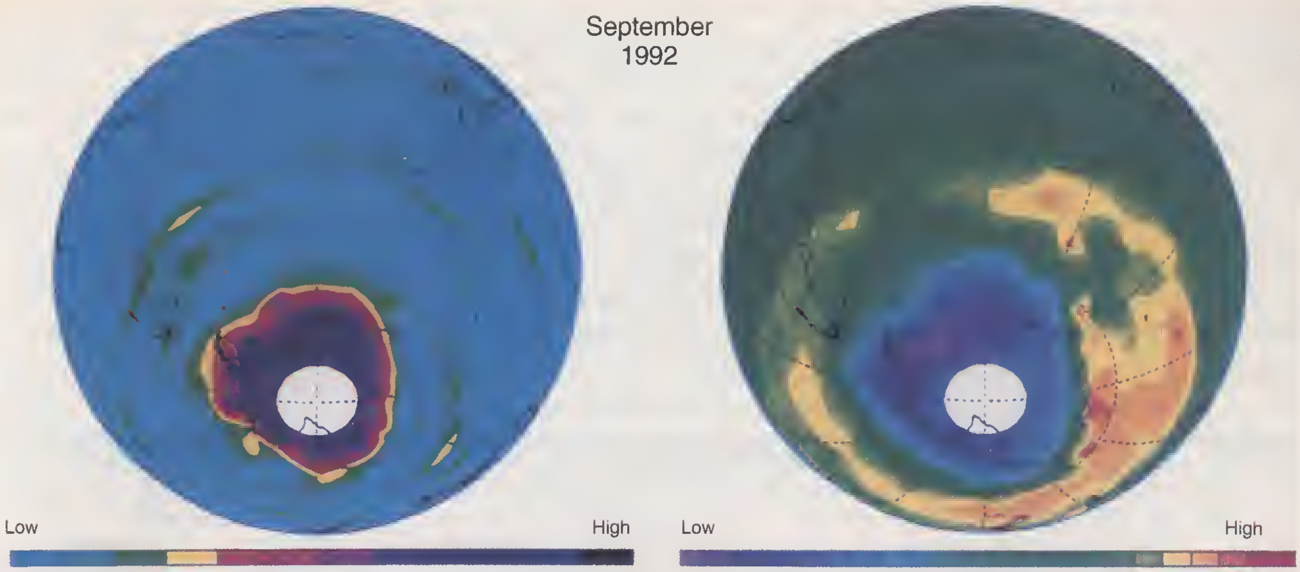
Rounding out the sensors on a well-equipped microwave radiometer platform would be an instrument designed to make vertical profiles of temperature. Such an instrument, or sounder, would use frequencies around 60 GHz, the so-called oxygen band. This is the frequency at which emissions from oxygen are most pronounced. In effect, the instrument measures the thermal emissions of atmospheric oxygen, and extrapolates from this information the average atmospheric temperature over some depth of atmosphere, perhaps half a dozen kilometers.

At about 60 GHz, the emissions from oxygen are so strong that the atmosphere is opaque after perhaps a few hundred meters. But as the frequency is reduced toward, say, 50 GHz, the range of received emissions is extended. A sounding, or depth profile, of temperature is achieved by making successively lengthy readings, each time factoring out the effects of nearer emissions.

U.S. satellite radiometers embodying one or more of the above principles include NASA's Nimbus satellites of the 1970s, some of NOAA's Tiros satellites, and the Defense Meteorological Support Program orbiters, most of which were launched in the 1980s (another is to be lofted in three years).

In fact, among the clear success stories in climate research of satellites originally designed for weather or environmental purposes are NOAA's Polar-Orbiting Operational Environmental Satellites. Their Microwave Sounding Unit has "proven to be a precise monitor of tropospheric temperature variations," according to Ohring of NOAA's National Environmental Satellite, Data, and Information Service. One of the unit's four microwave channels, at 53.74 GHz, provides surprisingly accurate temperature measurements of an important part of the atmosphere.

By taking many measurements as they orbit each day, these sensors have been supplying global average temperatures for much of the troposphere. Although the data go back only to 1979, in those 14 years the sensors have recorded perturbations to global temperatures caused by volcanic eruptions and other phenomena. "The important thing, I believe, is the fact that [the sensor] meets the requirement of mea-



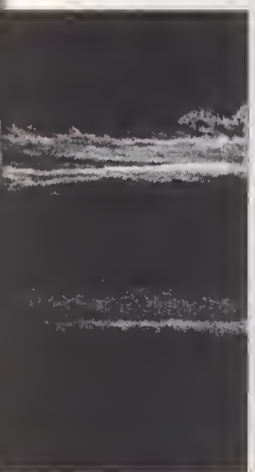
Jet Propulsion Laboratory

One of the most dramatic scientific discoveries of recent years was the annual depletion of ozone in a vast area of the upper atmosphere over the Antarctic. Last October this "hole" grew to almost the size of the North American continent. Shortly before this peak, the ozone above about 12 km [right] was plotted with the Microwave Limb Sounder, aboard the Upper Atmosphere Research Satellite. Chlorine monoxide, a key indicator of ozone depletion, was also mapped [left]; the image shows the gas about 20 km above the earth.

suring the small temperature trends associated with greenhouse warming," Ohring said.

OUT ON A LIMB. One of the most exciting applications of microwave radiometry, in Janssen's view, is the now-emerging science of limb sounding. This is also a passive technique, but instead of looking vertically through the atmosphere, the sensors are directed along a tangent, or "limb" in astronomers' parlance. The long line of sight through the atmosphere is needed to detect the faint emissions of sparsely distributed molecules in the stratosphere. The technique uses frequencies above 100 GHz to monitor the complex, ever-shifting chemistry of the stratosphere.

Limb sounding's newfound practicality is linked to several recent technological advances, including the increasing availability of planar diodes and compact, rugged, integrated electronics capable of reaching microwave frequencies and above. The technique is a timely tool for an alarming problem: monitoring the decay of the earth's ozone layer, the delicate stratum at about 30 km that protects all living things from the sun's fiercely carcinogenic ultraviolet radiation.



"One could not have written a science fiction story more dramatic than the discovery of the ozone hole," said Joe W. Waters, senior research scientist at Jet Propulsion Laboratory. Each year, the concentration of ozone in the upper atmosphere over a vast area above the Antarctic falls to disconcertingly low values. This ozone hole typically appears in early September and peaks in October; last year it grew to 23 million square kilometers, almost the size of the North American continent. It is caused by a series of complex chemical reactions, the main cause of which is chlorine in various forms.

Mostly from chlorofluorocarbons, "We've pumped six times the amount of chlorine into the stratosphere that's naturally there," Waters said. "Even if we stop now, it will take several centuries for the chlorine in the stratosphere to decay back to natural levels."

Apparently, more ozone is being destroyed than was thought, and the effects are showing up over Antarctica because the dynamics of the stratosphere do not replace it as quickly there, according to the University of California's Dozier. The seriousness of the situation was underscored by reports last April that ozone levels over the Northern Hemisphere were at their lowest levels in 14 years—10–20 percent below normal in the middle latitudes.

Such observations have made monitoring global stratospheric ozone a top priority. At present, researchers have at their disposal two operational limb sounders. One is aboard NASA's Upper Atmosphere Research Satellite (UARS), which was launched in September 1991. It was developed by Waters and others at the Jet Propulsion Laboratory (JPL), and has a 183-GHz radiometer built by the Rutherford Appleton Laboratory, Didcot, Oxfordshire, UK. The other operational limb sounder is the Millimeter-Wave Atmospheric Sounder, built by a German-led consortium. It has flown on two space shuttle missions, the latest one earlier this year.

Of the hundreds of molecules of interest in the chemistry of the upper atmosphere, current microwave technologies permit monitoring of about 25, according to Waters. Fortuitously, this group includes ozone, chlorine monoxide, and stratospheric water vapor, which have spectral lines at 206, 204, and 183 GHz, respectively. Of these three molecules, the most important for assessing ozone depletion by chlorine is chlorine monoxide, according to Waters. "Chlorine monoxide, in particular, is a direct measure of how fast ozone is being destroyed," he explained. The rate of ozone destruction is proportional to the square of the concentration of chlorine monoxide.

Using data from the UARS, Waters and colleagues at JPL have plotted striking color images of the annual sprawl of chlorine monoxide and the attendant obliteration of ozone over both polar regions [photos above]. They also have begun developing a much more sophisticated limb-sounding instrument, a linchpin of the chemistry mission of NASA's Earth Observing System. This instrument, to be launched with the chemistry satellite in 2002, will have sensors for frequencies ranging from 200 GHz to 2.5 terahertz; the latter is the approximate location of the best emission lines for the hydroxyl radical, OH. This radical is another key player in the complex chemistry of ozone destruction.

The instrument will be built with integrated microwave electronics and planar diodes, which far outdo the temperamental, hard-to-fabricate whisker-contacted diodes that have been used to date. "We're in the golden age of this now," said Waters. "We've learned so much from the UARS experiments and we're just starting to tap the surface of what can be done with this technique."

Microwaves are only the latest form of radiation to be used for detecting ozone concentrations. For years, researchers have used the Total Ozone Mapping Spectrometer, on NASA's Nimbus-7 satellite, and the Solar Backscatter Ultraviolet Radiometer, on NOAA's Polar-Orbiting Operational Environmental Satellites, to measure the ozone in vertical columns in the stratosphere. The atmosphere backscatters ultraviolet radiation into space, while atmospheric ozone absorbs the radiation, so measurements of backscattered UV are a good indication of ozone content.

DEEP BLUE SEE. Optical (visible-spectrum) sensors are also often combined with other types. In climatic and environmental research they are perhaps most valuable for estimating ocean productivity by sensing the color imparted to the water by microorganisms, an application known as ocean color. Standing in the way, literally, of the most accurate color readings is the entire atmosphere, if the readings are being made from a satellite. So near-infrared and other channels, where the ocean has no reflectance, are used to compensate for atmospheric effects on ocean color.

These readings are used to infer the density of phytoplankton in the water; basically, a greener color means more phytoplankton. This density in turn indicates productivity, the rate at which the minute plants are photosynthesizing. Productivity, finally, points to where carbon dioxide in the atmosphere goes, specifically, how much of it is used by the oceans.

The first ocean-color sensor was the Coastal Zone Color Scanner, which was launched on the Nimbus-7 platform in 1978 and operated until 1986. Another ocean-color sensor, the Sea-Viewing Wide Field Sensor (SeaWiFS), is now scheduled for launch some time in the first half of next year. Orbiting on SeaStar, a private-venture satellite, it will make highly precise visual and near-infrared observations around the globe. A similar instrument is planned for the EOS-Color mission in 1998.

Of great interest now to ocean-color specialists is whether the ultraviolet radiation shining through the Antarctic ozone hole is harming phytoplankton populations there, and the preliminary answer is yes. During an October 1990 cruise in the Antarctic Bellinghausen Sea, researchers measured photosynthesis and other indicators of phytoplankton production and found "a minimum 6 to 12 percent reduction in primary production associated with O_3 depletion." The team was led by researchers from the University of California's Marine Bio-Optics and Computer Systems Laboratory and from the Center for Remote Sensing and Environmental Optics, all in Santa Barbara.

Ocean color is just one of many techniques used to monitor the oceans' health, temperature, turbidity, circulation, and interactions with the atmosphere. These concerns are considered of such importance in understanding climate change that they are spread among the first, second, and fourth groups of scientific priorities identified by U.S. government researchers.

Why are these concerns so important? "The oceans are the place where we store heat," said Dozier. "In climate systems, the ocean is the flywheel. The key to understanding long-term climate changes has to lie in understanding the circulation of the oceans." Ocean-circulation patterns, however, are rather complex phenomena. They are influenced by many factors, including changes in river runoff and rainfall patterns, which alter salinity and therefore seawater density.

L'ENFANT TERRIBLE. One example of the strong link between ocean circulation and climate is El Niño, the eastward movement of excessively warm water across the Pacific. In effect, El Niño is a period during which the prevailing Pacific currents and trade winds weaken or even reverse direction, causing meteorological havoc throughout a vast area stretching from east Africa to the western Americas. Droughts in Australia and Indonesia, interrupted monsoons in India and Africa, and storms in normally placid regions of Micronesia and the western American coasts have all been blamed on El Niño. Recent floods in California, for example, are believed to be the result of an El Niño that had seemed over when it inexplicably revived in November 1992.

"There are correlations between ocean temperatures in the western Pacific and rainfall in western North America," Dozier said. "We don't understand the mechanisms, but, statistically, we certainly see the influence is there."

NOAA's Polar-Orbiting Operational Environmental Satellites have been used for years to infer circulation from the satellites' measurements of sea-surface temperatures. More recently, satellite radar altimetry has been used to produce quite precise maps of circulation patterns.

The U.S.-French Ocean Topography Experiment, also known as Topex/Poseidon, was launched in August 1992 by the Paris-based Centre National d'Etudes Spatiales aboard an Ariane vehicle. The satellite has a U.S.-built altimeter capable of measuring, to an accuracy of 10 cm, average ocean heights over tens of thousands of square kilometers. By comparing the average heights of adjacent regions, the direction of flow between them can be determined

Another chapter in international remote sensing will be written with the launch in 1996 of the first phase of the Advanced Earth Observing System (Adeos). This mission, the mainstay of the Japanese contribution to the international climate monitoring effort, will have a 14-GHz microwave system called Nscat (NASA Scatterometer). Nscat's measurements of the speed and direction of the winds over the surface of the global oceans, coupled with radar altimetry measurements of the roughness of the surfaces (from Topex/Poseidon or EOS altimetry, for example), will give indications of all sorts of exchanges between sky and sea. The most important of these transfers, as far as climate models are concerned, are those of momentum, mass, heat, water, and various gases, like carbon dioxide.

CASTING A PALL. Another big piece of the climate puzzle concerns aerosols, which are minute solid particles, sometimes covered by a liquid film, finely dispersed in the atmosphere. Their origin is sometimes natural, sometimes not. Although not nearly as productive as a giant volcanic eruption, the main man-made sources of aerosols are fossil fuel combustion and so-called biomass burning, the routine combustion of plant matter when forests are cleared for agriculture or construction. Biomass burning occurs mostly in South America, Africa, and Indonesia.

The two chief goals of aerosol research were spelled out for *Spectrum* by Brent Holben, an aerosols expert in the Biosphere Sciences branch at Goddard Space Flight Center. One is to determine the effects of aerosols on solar radiance—how they scatter and absorb the sun's rays, and so on. The second goal is better characterization of the aerosols' optical effects, so that they may be factored out of the views obtained from satellites of underlying vegetation.

It is now believed that during the burning season, aerosols cause a 5–12 percent reduction in the solar radiation that reaches the earth's surface, Holben said. Nonetheless, "it's not clear whether they're heating the atmosphere or cooling it," he added. Like clouds, aerosols reflect solar radiation back to space, but they also absorb a lot of it, thereby warming the atmosphere but cooling the earth's surface. Thus the effect of aerosols on climate is significant; after all, as one researcher put it, climate is "the long-term average of the processes by which the planet redistributes solar energy before re-emitting it to space."

The effects of aerosols have been thrust very much into the mainstream of climatological research, thanks to a pair of volcanoes named Pinatubo and El Chichón. The eruptions of the two, in the Philippines in 1991 and in Mexico in 1982, respectively, may have tossed enough sulfur into the atmosphere to partly obscure global warming trends, according to some researchers. Aerosols linked to the mammoth explosion of Pinatubo alone may have lowered the average global temperature by half a degree.

"There is conjecture that the effects of these eruptions, plus biomass burning, may be producing a screen of aerosols causing a cooling influence that may be offsetting the warming trend," said John A. Reagan, a remote sensing expert and professor at the University of Arizona in Tucson. "There's a need to make measurements to pin this down. All the data simply are not there to prove it." The fear is of a shift in the

balance, as when the aerosols settle out of the atmosphere, suddenly changing average temperatures.

Detection of aerosols is fairly straightforward. Basically, the orbiting sensors are aimed at a large lake, ocean, or some other dark background on the earth's surface. Brightening of the image is attributed to sunlight reflecting off aerosols, clouds, and other atmospheric components. The proportion of aerosols is estimated from the use of various infrared or visible-spectrum bands, which are scattered in a known, characteristic manner by the relatively large aerosol particles.

The main instruments used to date for aerosol studies are NOAA's Advanced Very High Resolution Radiometers, which have been flying on the agency's Polar-Orbiting Operational Environmental Satellites since 1979. The AVHRR, as it is known, has three infrared and two solar-reflective sensors.

After years as something of a bit player in climatology, aerosol research appears headed for star billing in the EOS program. Monitoring of aerosols will be accomplished by no fewer than four major sensors: the Moderate-Resolution Imaging Spectroradiometer and the Multi-Angle Imaging Spectroradiometer, both on EOS-AM; the Earth Observing Scanning Polarimeter on EOS-AM2; and the Stratospheric Aerosol and Gas Experiment III, on both EOS-Aero and EOS-Chem.

This last sensor, which employs an unusual and very direct mode of remote sensing, is an improvement on one that has flown on the Earth Radiation Budget Satellite, launched from the space shuttle

An abridged guide to climatic remote sensing

In operation

Sensor	Satellite(s), first launch	Builder (overseer)	Spectral bands	Monitoring uses
Advanced Very High Resolution Radiometer	Polar-Orbiting Operational Environmental Satellites, 1978	ITT (National Oceanic and Atmospheric Administration, NOAA)	Visible, infrared	Aerosol concentrations, sea-surface temperature, clouds, snow cover, vegetation index
Tiros Operational Vertical Sounder (TOVS)		ITT (NOAA)	Infrared	Cloud water and vapor, temperature profiles
TOVS Microwave Sounding Unit		Aerojet Electronic Systems Division (NOAA)	Microwave	Precise tropospheric temperature measurements[a]
Solar Backscatter Ultraviolet Radiometer	Polar-Orbiting Operational Env. Satellites, 1985	Ball Corp.'s Aerospace Systems Group (NOAA)	Ultraviolet	Ozone concentrations
Synthetic Aperture Radar	European Remote-Sensing Satellite–1, 1991	Marconi (European Space Agency)	Microwave	Land/sea ice, vegetation, clear-cutting and boreal forest fires
Microwave Limb Sounder	Upper Atmosphere Research Satellite, 1991	Jet Propulsion Laboratory, JPL (NASA)	Microwave	Concentrations of ozone and other trace gases in the stratosphere and upper troposphere[a]
Altimeter	Topex/Poseidon, 1992	JPL and Centre National d'Etudes Spatiales	Microwave	Sea-surface height

Coming shortly

Sensor	Satellite(s), first launch	Builder (overseer)	Spectral bands	Monitoring uses
Sea-Viewing Wide Field Sensor	SeaStar, 1994; (possibly EOS-Color, 1998)	Hughes Santa Barbara Research Center (Orbital Sciences Corp.)	Visible, near-infrared	Ocean productivity, physics, and chemistry
Synthetic Aperture Radar	Radarsat,1995	Spar Space Systems (Canadian Space Agency)	Microwave	Land/sea ice, vegetation, clear-cutting and boreal forest fires
Precipitation Radar	Tropical Rainfall Measuring Mission, 1997	Japan's National Space Development Agency and Communications Research Laboratory	Microwave	Precipitation intensities (rain rate)
Measurement of Pollution in the Troposphere[a]	EOS-AM, 1998	COM DEV Ltd. (Canadian Space Agency)	Infrared, microwave	Concentrations of methane, vertical profiles of CO concentration
Advanced Spaceborne Thermal Emission and Reflection Radiometer		NEC (Ministry of International Trade and Industry, Japan)	Visible and near-infrared, shortwave, and thermal infrared	Surface temperature, spectral emissivity
Multi-Angle Imaging Spectroradiometer		JPL	Visible, near-infrared	Aerosol concentrations, slash-&-burn agriculture, desertification
Moderate-Resolution Imaging Spectroradiometer	EOS-AM, 1998; EOS-PM, 2000	Hughes Santa Barbara Research Center (NASA)	Visible, infrared	Surface temperature, ocean color, vegetation and snow cover, cloud cover and properties, aerosols, fires, precipitable water
Atmospheric Infra Red Sounder	EOS-PM, 2000	Loral, JPL (NASA)	Infrared	Temperature and humidity profiles, surface temperature, radiance, cloud properties
Multifrequency Imaging Microwave Radiometer		Alenia, Italy (European Space Agency)	Microwave	Precipitation, cloud water and vapor, sea conditions, surface ice
Stratospheric Aerosol and Gas Experiment III	EOS-Aero, 2000; EOS-Chem, 2002	Ball Aerospace (NASA)	Visible, infrared	Trace gas and aerosol concentrations in the mesosphere, stratosphere, and upper troposphere[a]
Microwave Limb Sounder	EOS-Chem, 2002	JPL (NASA)	Microwave	Chemistry of the stratosphere and upper troposphere[a]

Source: *1993 EOS Reference Handbook* and *Space-Based Global Change Observation System Program Plan*, both from NASA Earth Science Support Office; interviews
a Atmospheric layers extending through the lowest 11–16 km (troposphere), from the troposphere to 45–50 km (stratosphere), and from the stratosphere to 85–90 km (mesosphere).

Microwave sensors can now be used to distinguish among water vapor, liquid water in clouds, and even rainfall to some extent. This composite image shows the average distributions of water vapor and rainfall in August 1988. Sensed over the oceans with a resolution of 50 km, the water vapor varies from about 1 g/cm² [dark blue] to more than 5 g/cm² [lighter blue]. The rainfall [yellow] was detected over land and ocean at a resolution of about 15 km. The image was made by comparing and contrasting data gathered with receivers sensitive to 19, 22, 37, and 85 GHz, and orbited under the Defense Meteorological Satellite Program.

Challenger in 1984. While the sun is high above the horizon, the sensor scans across it. Then, as the sun sets or rises, the sensor scans the glowing disk through the atmosphere, extracting from the image aerosol properties and trace gas concentrations, but only in the stratosphere and upper troposphere. The sensor will see 15 sunsets and sunrises a day, each in a slightly different place. It will also look at the moonrises and moonsets for much the same information.

MYSTERIOUS METHANE. Aerosols are far from the only big puzzle in climate research. One of the most important and least understood issues in climate change is the chemistry of the troposphere, the part of the atmosphere extending from the earth's surface to the stratosphere. "The chemistry of the trophosphere is much harder to measure from space than that of the stratosphere, because of the clouds and water vapor," according to Dozier. Of particular interest are the greenhouse gases, such as methane and the various carbon-based gases, and the exchange of the latter between the atmosphere and jungles, forests, and other terrestrial gas-sinks.

Methane is an uncommon mystery. Its concentrations are a minuscule fraction of those of carbon dioxide. Nonetheless, of the 3–5 °C temperature rise possible by the middle of the next century, methane could account for one full degree, vs. one and a half for carbon dioxide and one for water vapor. The main reason is that methane soaks up infrared—volume for volume, about 20 times more than carbon dioxide.

Methane concentrations are also increasing at a mystifyingly rapid rate: 1 percent annually—twice that of carbon dioxide. Scientists are at a loss to explain the trend, since the main sources of methane—rice paddies, wetlands, much-discussed bovine flatulence—cannot account for it. A consensus is growing that the sinks for the gas must somehow be failing, but the theory is hard to prove because scientists do not know exactly what the sinks are. "It may be the OH radical," said Dozier. "But there are all sorts of other things that can take up the OH radical, like carbon monoxide."

At present, satellites with instruments that can shed light on such perplexities are practically nonexistent. Between 1998 and 2002, however, a host of EOS satellites will be launched with instruments useful for these very questions. This august group of orbiters will include Adeos, EOS-Chem, EOS-Aero, EOS-AM, and the European POEM-Envisat.

SATELLITE OF ALL TRADES. The first and most versatile of the EOS platforms will be the EOS-AM series, which will be among the most ambitious remote-sensing satellites ever built. With an initial launch scheduled for the second quarter of 1998, EOS-AM will carry six types of advanced sensors, each with a five-year lifetime. There will be three separately launched platforms in the series, with a cumulative expected life of 15 years. The centerpiece sensor will be the Moderate-Resolution Imaging Spectroradiometer (Modis), which is being developed for NASA at a cost of about $135 million by Hughes Corp.'s Santa Barbara Research Center, in Goleta, CA.

The 0.4-m³, 250-kg Modis instrument will have 36 thermal infrared and solar-reflective channels for collecting data on surface temperature; ocean color; vegetation, snow, and cloud cover; cloud and aerosol properties; fires; and global distribution of precipitable water. This one instrument will generate about 600 billion bits per day. Modis will also fly on the slightly less far-reaching EOS-PM series of satellites.

For tropospheric chemistry, EOS-AM will carry a sensor called Mopitt (Measurement of Pollution in the Troposphere), which is being built in Canada under the supervision of the Canadian Space Agency. The sensor will monitor thermal and reflected solar channels to determine the vertical profile of carbon monoxide, as well as the total abundance of methane in a vertical column. In the second and third phases of the EOS-AM series, Mopitt will be joined by the Tropospheric Emission Spectrometer. It will monitor a wider range of frequencies to detect more molecules, including nitrogen oxides, ozone, water vapor, and sulfur dioxide.

Also of note on the AM platform is the Advanced Spaceborne Thermal Emission and Reflection Radiometer, being built under the aegis of the Japanese Ministry of International Trade and Industry. Aster will monitor much the same biological and physical processes as Modis, but with much greater spatial resolution (15–90 meters as opposed to 250–1000 meters). This kind of resolution comes at a price, namely, narrower swath and data rates of 200–300 Mb/s. So the sensor will be operated much more sparingly than Modis. According to William L. Barnes of Goddard's Laboratory for Hydrospheric Processes, it will be used primarily for select targets of interest—forest fires or floods, for example.

ACTIVE SENSING. Although virtually all environmental remote sensing has been done with passive sensors, active instruments are starting to make their mark. "We started out with passive visible and infrared, and expanded into passive microwave, which is still being developed," said Ohring, of NOAA's National Environmental Satellite Data and

Information Service. "And we're headed toward active systems."

Several active instruments are already in orbit; one example is the altimeter on the Topex/Poseidon, which measures sea-surface height. An emerging crop of radar and lidar (light detection and ranging) instruments will take this trend a step further, providing invaluable data on ice at sea and on land, oceanographic phenomena, coastal erosion, vegetative cover, geological features, cloud content and physics, trace gases, aerosol concentrations, wind fields, and barometric pressure.

The advantages of these active sensors include the fact that the emitted signal is well known, and can therefore be precisely compared with the return signals to extract subtle phenomena. The quality of the signal can also be monitored at its source, and the emissions can be tailored to achieve specific goals. Challenges include generating the power needed to transmit signals from the satellite, where power is always at a premium. Other concerns include durability and, for lidar, the stability of the laser's spectral frequency.

At present, there are two satellites, the European Remote-Sensing Satellite (ERS-1) and Japan's Earth Resources Satellite (JERS-1), equipped with synthetic-aperture radar (SAR), which exploits the motion of the platform to make high-resolution radar images of scenes on the ground. This type of radar illuminates the same scene with a large number of pulses as it passes over, extracting the data to reconstruct the surface from the time-of-flight and the Doppler-shifted frequency of the return signals.

So far, synthetic-aperture radar has been used mainly to monitor the type, condition, and velocity of the great ice sheets and of the sea ice on the polar oceans. "Those account for, probably, the use of at least half of the SAR data now being generated," said Frank Carsey, a researcher at Jet Propulsion Laboratory. He explained that the link to climate research is the heavy dependence of polar-ocean heat loss on ice cover, specifically, how ice deforms as the wind blows it around the polar seas and from the polar oceans to more temperate ones. Ice deformation exposes stretches of water to the frigid polar air. Intensive ice growth in these open water areas injects brine into the upper ocean, changing the density of the water and hence the polar circulation patterns.

Other developing uses for the radars include monitoring clear-cutting of tropical and mid-latitude forests, as well as the burning-rate of more northern boreal forests, which are largely coniferous. Portions of these forests catch fire sporadically, and so often that over a few decades all of them have burned at least once. An edge the radars have in monitoring deforestation is their ability to see through clouds, which hinder optical or infrared methods.

The next milestone in synthetic-aperture radar sensing will be the 1995 launch of Radarsat, being built by Spar Space Systems, near Montreal. Radarsat will view a 500-km swath—five times the width of the ERS-1's swath. Such a feature will let researchers monitor rather than merely sample various phenomena. Radarsat will also do the first mapping of the Antarctic ice sheet.

ILLUMINATING INSTRUMENT. Lidar is another active instrument with a bright future, as far as some researchers are concerned. As a remote-sensing technology, lidar certainly promises extraordinary versatility: it may be used to make images of clouds to show their extent and patterns; reveal cloud contents and optical properties; measure aerosols, pollutants, and trace gases like ozone; do temperature and water-vapor soundings; and monitor wind fields and pressure.

So far, however, this active instrument has been used in a limited number of experiments conducted from the ground or an aircraft, although a lidar experiment is scheduled to fly on the space shuttle next year. Shuttle astronauts hope to employ a lidar system to measure atmospheric aerosol concentrations, temperature, pressure, and cloud heights.

Several lidars were recently used to make some remarkable discoveries about cirrus clouds, those wispy thin, fast-moving, and diffuse denizens of the high troposphere [see photo, pp. 20–21]. At these lofty heights, cirrus clouds, popularly known as mares' tails, tend to consist mostly of ice crystals, and therefore play a complex role in the planet's radiation budget. Ice can be highly reflective, rejecting heat into space. But it can also intercept the earth's own infrared emissions, and any phase changes—when the ice crystals melt or sublimate, for example—could seriously upset the radiation budget, changing the reflectivity and absorbing or releasing heat.

> Even with no more chlorine emissions, it will take atmospheric concentrations centuries to return to normal

With funding from the National Science Foundation (NSF) and the Department of Energy, researchers at the University of Utah in Salt Lake City have built a lidar system in which the polarization of the return signal can be analyzed, letting researchers estimate the proportions of water and ice in clouds. Since they are spheres, tiny droplets of water tend to scatter polarized rays without changing their polarization, whereas ice crystals change the orientation of the polarization.

Late in 1991, Kenneth Sassen and colleagues at the university's department of meteorology used a polarimetric lidar to analyze cirrus clouds over Kansas. They found not only ice crystals but, surprisingly, also liquid water drops in clouds at temperatures as low as −48.7 °C. Sassen theorizes that stratospheric aerosols from the eruption of Mount Pinatubo mixed with the cirrus clouds in the troposphere, creating particles that dissolved in the water droplets, inhibiting freezing.

"Here is, in fact, a connection, we think, between volcanism and cloud composition," said Ronald C. Taylor, program director of physical meteorology at the NSF. "A few water drops at these heights could change the radiation budget of a whole layer of air. This is an immensely important tool for helping to define the problem."

A LONGER VIEW. Despite such encouraging advances, researchers caution that many unknowns remain—far too many to be addressed by EOS and its international affiliates during their decade-and-a-half collaboration. Other than estimations from satellites, for example, actual rainfall over oceans is not measured in any regular way. Nor is there any reliable technique at present, or even plans afoot, for monitoring soil moisture, an extremely important parameter for understanding the effects on agriculture of other changes, and the earth's vitally important hydrological cycle in general.

"EOS is only a 15-year program designed to make many measurements in an intensive effort to understand the earth," said NOAA's Ohring. "But for long-term monitoring, you need continuous measurements over decades, with high accuracy for both response and forcing variables. That's a challenge."

Forcing variables, also known as forcing factors, are the external drivers of climate change. Some examples are volcanic activity, irregularities in solar radiation, greenhouse gas emission, and biomass burning.

"I think a point could be made that we do not yet have, and will not have even with EOS, the system in space for monitoring long-term global change. By long term, I mean a decade-to-a-century time scale."

As a step toward this goal, longer satellite lifetimes would be a helpful start. "With the lifetimes of satellites at three to five years, it would be nice if one could develop satellites and instruments that have lifetimes of 20 years, with communications, power, all the things that support the system in space, with 20-year lifetimes," Ohring observed. As a goal for the future, we must lengthen the lifetimes, so we don't have to worry about so many discontinuities in the record." ◆

Dealing with the data deluge

A record torrent of data has to be made readily accessible to a growing international community of global-change researchers and policy makers

By the year 2000, satellites deployed by the National Aeronautics and Space Administration will be transmitting 1 terabyte of data to earth every day. If stored on magnetic tape, this daily deluge would require a stack of reels as high as the 169-meter Washington monument in the U.S. capital. Clearly, traditional methods of collecting and managing data and information might well be overwhelmed by this enormous quantity of remotely sensed data and information about the earth and its oceans and atmosphere.

So the space agency, with the help of other organizations, is developing the most ambitious data and information system ever built. Besides the sheer volume of data it will handle, it will have to deal with complex and diverse data and the different demands and work styles of the scientists who will use its resources.

The need for continuous comprehensive observations of the planet is urgent. With their aid, a better understanding can be achieved of the potentially hazardous impact of human activities on the environment.

But when the data are so complex and voluminous and require complicated algorithms for processing and visualization, important phenomena described by them may be overlooked or get lost. A good example is the delayed discovery of the ozone hole over Antarctica. The hole was spotted by British researchers in 1985 through direct measurement, even though the information to establish its existence had been in data stored in the United States for years.

In 1990, therefore, the U.S. government took its first step toward a better grasp of the issues involved in global change and established the U.S. Global Change Research Program, whose job it is to work with the national and international scientific communities. Mission to Planet Earth is the contribution to this program made by the National Aeronautics and Space Administration (NASA). It includes ongoing, near-future, and longer-term satellite sensor missions; the management and analysis of remotely sensed and *in situ* data; and the administration of a basic research program on global changes.

Nahum D. Gershon and C. Grant Miller
The Mitre Corp.

The Earth Observing System (EOS), the centerpiece of the Mission to Planet Earth, will be a series of polar-orbiting satellites making extended observations of the earth and its environment. (The first few earth science satellites were launched recently, but the EOS satellites themselves are awaiting launch in the 1998–2010 time frame.) Finally, the Earth Observing System Data and Information System (Eosdis) will manage the mountains of EOS and earth-science satellite data and will also handle the harvesting and sharing of information, the dissemination of ideas, and the establishment of a community of collaborators that will be professionally close-knit but geographically dispersed both in the United States and elsewhere.

Eosdis' primary mission is to provide the global-change research community with quick and easy access to the data. In addition to earth science data from EOS spacecraft, Eosdis will include data from other NASA earth science missions, as well as from non-NASA and cooperative international missions. It is intended to process, archive, manage, and distribute the data, and even provide for command and control of EOS spacecraft and instruments.

NASA, helped by other agencies, is building the most ambitious data and information system ever

IN THE BEGINNING. Though the goals for Eosdis' size and capabilities will be revolutionary, its development are to be evolutionary. The focus will be on ensuring that existing and emerging key data sets are preserved and made readily accessible. Data sets relevant to global-change research have been, and are being, adapted for inclusion in eight Distributed Active Archive Centers (DAACs) throughout the United States [see map, opposite], as well as in non-NASA–funded data centers that will be accessible to Eosdis users.

In the last three months of 1992, the DAACs were already filling over 1300 orders for data. Approximately 60 000 additional orders for data were filled by the U.S. Geological Survey's Global Land Information System.

One of the eight DAACs, at the Goddard Space Flight Center, Greenbelt, MD, will build on the scientific expertise and institutional heritage of NASA's Climate Data System, which was located there. That climate system was an integrated one supporting atmospheric, ocean, and earth science researchers by allowing them to interactively locate, access, manipulate, and display climate-related data. It also provided access to catalogs of data descriptions and an inventory of temporal and volume information. After many years of development, the data and functional capabilities of this system are being passed on to the Goddard DAAC.

Besides using data sets from the eight data centers and data systems already in existence, Eosdis will help in identifying and generating Pathfinder data sets. Created from satellite data intended primarily for meteorological and environmental purposes, many of these sets have been designed to support global-change research. Among the satellites contributing to these Pathfinder data sets are the National Oceanic and Atmospheric Administration's Advanced Very-High Resolution Radiometer, Landsat Multispectral Scanner, and Thematic Mapper.

How far along is Eosdis itself? Although the full-capacity Version 2 is scheduled for 1998, an initial Version 0 has been under construction since 1991 by the Earth Science Data and Information System Project Office at NASA's Goddard Space Flight Center and the Distributed Active Archive Centers and is now being evaluated.

This working prototype's operating elements will be officially released to users in 1994. It will continue the existing services of the various data centers while improving access to data. Version 0 will prototype the integration of services across these centers

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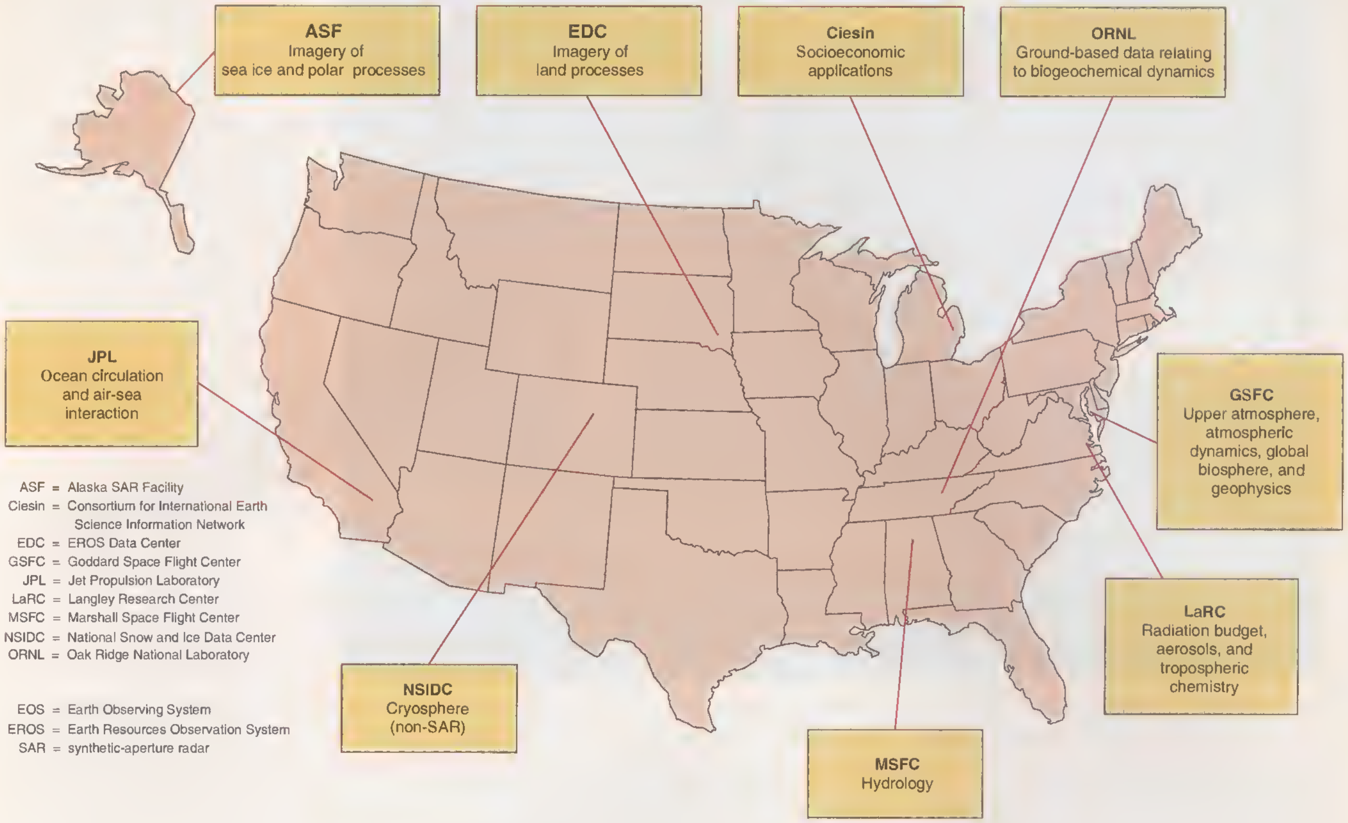
Eosdis Distributed Active Archive Centers



[1] The eight Distributed Active Archive Centers that are part of the Earth Observing System Data and Information System (Eosdis) are scattered all over the United States, to take advantage of the local earth science expertise and institutional heritage. The end-user access to these disparate centers is facilitated by the pioneering Eosdis Version 0 system and various communication networks. Ciesin is an additional data center, providing socioeconomic data

to provide users with a unified earth sciences view. Many of these features were suggested by the future users of the data and information system, who have been intimately involved from the very beginning with the development of all stages of Version 0.

Under this version, a single user interface lets researchers search for data across all the DAACs. Furthermore, Version 0 will employ graphics to provide a simple, effective means of obtaining information about the data sets [see photograph, overleaf]. Scientists will be able to search for data by geographic area and time period, as well as by such characteristics as data source or geophysical parameters.

In addition, users may browse through samples of the data displayed on the computer screen. The prototype system also offers "one-stop shopping": once the user has determined what data are of interest, he or she may use this interface to request data from all centers without having to access multiple systems.

MASTER DIRECTORY. A number of useful features have been designed or are planned to guide users through the thickets of data and on-line information sources. One, a pioneering system developed by NASA and called the Global Change Master Directory, helps users locate data sets of interest among the massive and diverse earth science data sets. It is supporting Version 0 and will support succeeding Eosdis versions.

The main purpose of the Global Change Master Directory is to provide a brief survey of NASA and important non-NASA data and on-line information systems dealing with space and earth science, so that users may quickly determine what data and information sets would best suit a given task.

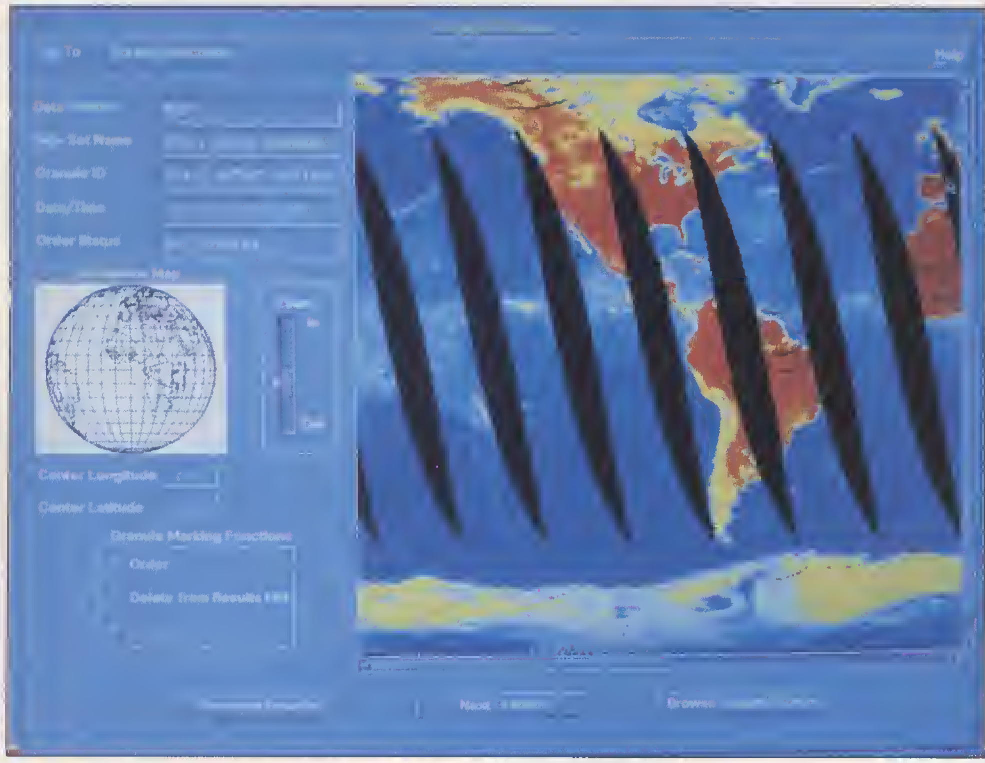
The Global Change Master Directory includes brief descriptions of the contents of data and information sets, as well as location and points of contact for off-line ordering, plus possible quality assessments and relevant publications. The directory often connects automatically to on-line information systems where more details about data sets of interest may be obtained. Often, the user may directly access or order the data through these on-line systems.

EOSDIS: THE FUTURE. Currently, the builders of Eosdis are adding capabilities to Version 0 and developing Version 1, to guarantee the quality and range of services vital to the first EOS flight. As it evolves through subsequent versions, Eosdis will need to facilitate the acquisition, processing, archiving, management, and distribution of the large volumes of data from the growing fleet of EOS instruments. During the next 20 years, Eosdis is expected to handle data from all NASA earth science satellites.

For EOS satellites, Eosdis will also convert raw data into standard data products. Remotely sensed measurements (of, say, the amount of thermal radiation emitted by the ocean surface) will be transformed into physical quantities readily usable by researchers (sea-surface temperature, in this case).

Eosdis will also assist in command and control of the satellites and their instruments: it will make orbit and attitude adjustments, and direct and schedule the operation of instruments. For non-NASA satellites, Eosdis will enable access to some of the archives and distribution systems of the responsible agencies, such as the National Oceanic and Atmospheric Administration (NOAA).

The jobs of generating standard data products and archiving, distributing, and managing all earth science data will be performed by the DAACs. These centers will continue to serve traditional researchers whose needs are confined to specific parameters (trace gas concentrations in the



National Aeronautics and Space Administration

[2] The right half of an interactive screen from the Eosdis Version 0 shows a low-resolution version of the original SSM/I antenna temperature data. The new version occupies much less volume and thus could be transmitted relatively quickly. Nevertheless, it could assist the user in selecting the required data for his or her research. For example, those who need data on the Chesapeake Bay on the U.S. East Coast would not order the full-resolution data corresponding to this image. The data for this image are archived at NASA's George C. Marshall Space Flight Center in Alabama. [The black areas in this image represent areas where data were not collected.]

stratosphere, for example), as well as researchers whose needs cut across discipline boundaries, combining oceanographic and atmospheric information, say.

Eosdis is being built with a distributed, open-system architecture. Thus Eosdis elements are sited at various locations, to better utilize different institutions' capabilities and scientific expertise. This approach also builds on existing system capabilities, spreads technical risk in developing the system, and helps avoid a single point of failure. Although Eosdis is physically distributed, it will appear as a single logical entity to the user [Fig. 3].

Two levels of electronic networks will connect the primary Eosdis components, distributed systems, and end users. Internal networks will use NASA's own communication resources for secure, reliable interconnection of the Eosdis elements. Such interconnection is required for the seamless functioning demanded by the command and control of spacecraft, and for a uniform user view of the system. External networks will support end-user access to the system. For these, NASA is employing existing resources to the extent possible, including resources of the NASA Science Internet and its connections to the National Science Foundation Internet, and the planned National Research and Education Network (now under development).

USER INVOLVEMENT. Future users of Eosdis have been involved in several aspects of its development. At the outset of the project, the data and information needs of global-change researchers were identified by an investigatory working group. These needs were then used to develop the designs and data-production systems of the EOS instruments. Researchers are developing the algorithms and parameters of the data products that will be stored by Eosdis and made available to all researchers. Users also have been intimately involved, through an investigator advisory panel, in guiding system development and operation.

This broad user-community involvement is reflected in the diversity of support that Eosdis will offer. For environmental researchers, who will be the primary user community, Science Computing Facilities will support computational requirements and the user interface. Funding for the communications and computational equipment that is required (the latter ranging

A new era in international cooperation

One of the challenges of international cooperation on data and information systems is the need to bridge not only different technical approaches, but also different styles of user queries based on disparate cultures and backgrounds. However, there are some promising new beginnings.

The U.S. Global Change Data and Information System (GCDIS) is expected to be part of a truly international global change data and information system. The international Committee on Earth Observing Satellites (CEOS) and its working group on data coordinate the cooperation of different international partners. And several subgroups provide forums for technical coordination and the development of specific abilities, including catalog, format, networks, and data access.

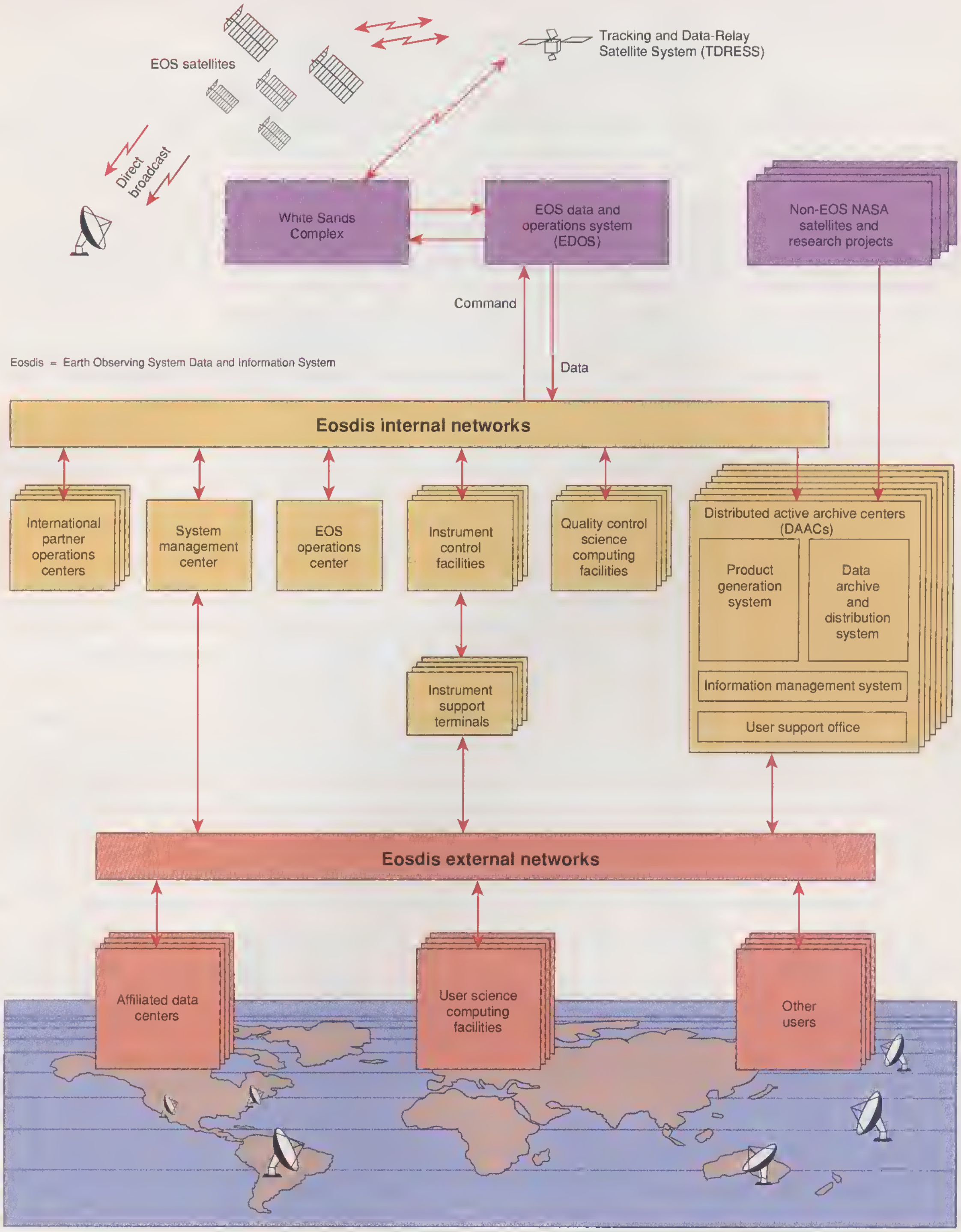
Some significant achievements of these subgroups are adoption of the Global Change Master Directory [see text, p. 32] as the international directory standard, and network experiments among the United States, Europe, Japan, and other areas to test connectivity and interoperability for catalog and data transfer functions. A format subgroup is holding continuing discussions toward developing standard data formats for science discipline data products. The U.S. agency participants in the CEOS committees provide coordination, continuity, and consistency with the U.S. GCDIS program.

On the horizon is CEOS's Catalog Interoperability Experiment, or Cintex, an experimental prototype designed to promote international cooperation. It will provide access to international partner earth-observing data and information systems from a single interface installed on a desktop workstation. Cintex participants are NASA, the European Space Agency, the United Kingdom's Defence Research Agency, and the German Research Institute for Air and Space. Currently, Cintex is developing an interface between Eosdis Version 0 and a system called the User Interface Terminal of the European Space Agency.

One flexible graphical user interface enables the User Interface Terminal to provide easy access to multiple earth observation information and data-order services. To search for the availability of data sets, users can choose the required time domain by interacting graphically with a calendar time line, and then select the required spatial region by using a map and drawing a polygon around the area of interest. These interactions are performed with the aid of an intuitive point-and-click interface. In addition, the user can define other criteria by choosing, for example, keywords. The results of the search are readily visualized, and though the data sets that can currently be accessed using this terminal are limited, the number is expected to increase.

—N.G. and G.M.

EOS Data and Information System architecture



[3] The evolving Eosdis architecture has many components distributed throughout the United States and connected by internal and external communications networks. The architecture supports, for example, connectivity to affiliated data centers and international resources, command and control of spacecraft and instruments, generation of data products, and data archiving and retrieval.

from workstations to supercomputers) will come from a variety of sources located both within and outside NASA.

The Earth Observing System Data and Information System is planning to provide software packages for accessing Eosdis. These software toolkits will let researchers access Eosdis services from readily affordable personal computers. Of course, this type of terminal will not be able to match the speed and sophistication of more powerful workstations, but it will help make the basic services available to the widest possible group of users—even those who possess only a PC and a modem.

Eosdis has also had the benefit of extensive review from a wide range of committees, including the National Academy of Sciences, the Office of Technology Assessment, and the General Accounting Office. Efforts to address these recommendations have considerably strengthened Eosdis development.

PUTTING IT TOGETHER. A significant technical challenge facing Eosdis designers is knitting together the many disparate databases of use to global-change researchers. NASA, NOAA, the U.S. Geological Survey, the Department of Energy, and other U.S. govern-

ment agencies currently support a broad assortment of data and information resources related to global-change research. Even in cases where these resources are available for research, they are generally managed for their own agency's specific objectives. In addition, these data can be used to create an invaluable baseline against which global climate change may be measured.

The goal of the Global Change Data and Information System (Gcdis) is to coordinate the activities of these and other agencies participating in the U.S. Global Change Research Program, so that global-change data and information, including those outside Eosdis, can be easily accessed and used. This system will exploit the diverse and distributed resources and missions of these agencies by connecting their data and information holdings to one another and to the user community. The result will be an integrated, comprehensive view of these collective holdings, supporting policies, and services.

Gcdis will provide access to international data and information holders, providers, and users. Initially, this access will be provided by the World Data Center systems (sponsored by the International Council of Scientific Unions). This system is responsible for the archive and exchange of important environmental data and information among all nations. Currently, a number of agency data centers participate in this system for a broad range of global-change data and information.

The scope of data and information being considered for the Gcdis includes the earth science data holdings of the agencies (*in situ* and remotely sensed data), selected output from global-change models, and socioeconomic data (population, economic systems, and political systems and institutions)—all necessary for the study of the human dimensions of global change.

One of the sources for the Gcdis, and the one with the longest temporal span, is NOAA's National Climatic Data Center, which has observations on the weather dating back over a hundred years. Its mission is to manage global and environmental data supporting global-change research, as well as state and regional climate centers and commercial clients. Current holdings amount to approximately 140 terabytes, most of which is satellite imagery. NOAA expects its next-generation weather radar system to yield 80–90 terabytes of data per year, and its future geostationary and polar satellites to generate data even faster.

Federal agencies will coordinate the procedures for searching data and handling orders for data products. They will also help make data and information on global change available in forms compatible with users' needs. Other services provided by this cooperative action include user interface, information about the data (catalogs, for example), and the ability to browse through the data, as well as documentation and archival standards.

The Global Change Master Directory has been adopted as an integral component of Gcdis Though the majority of system users are expected to be global-change researchers, there will also be other researchers, policy makers, educators, researchers in private industry, and private citizens.

Understanding the causes and magnitude of global change calls for collecting and managing unprecedented volumes of data and information. But dealing with this quantity and the complexity will boost the state of the art in information technology and its applications.

Before achieving the stated goals of the international global-change research agenda, however, breakthroughs must be realized in facilitating user access to data (cataloging and browsing), storing and retrieving data, and coordinating the developer and user communities. Eosdis must evolve to accommodate new technologies as they become available. Success will also require high levels of interagency and international cooperation.

If successful, the payoffs of this high-profile, large-scale effort could be exceptional, and not just for the vital global-change research. Advances in data and information management needed for this research could benefit other areas as well, including the Human Genome Project, the Human Brain Project, radiology, and distributed medical collaboration (telemedicine), to name just a few. ◆

Pushing the state of the art even further

As if dealing with massive amounts of data and information were not enough, both earth science data and the query style of researchers are complex.

Tools that address these difficulties are being built by Sequoia 2000, Digital Equipment Corp.'s "flagship" external project involving computer scientists and earth scientists at five campuses of the University of California. Hardware and software are being designed and developed to handle huge quantities of data, large objects, distributed archives, and diverse data types—including satellite images, output from global circulation models, river basins and networks, hydrological and meteorological stations, and texts and programs.

Sequoia 2000 will allow an advanced query style that supports questions researchers often ask, such as "Find ultraviolet solar irradiance at ocean surface under Ozone Hole in an ice-free area on Oct. 30, 1992." It will also support integrated and intelligent visualization and analysis tools, as well as rapid browsing over networks through remote, distributed storage.

Another project concerned with some of these issues is being carried out at The Mitre Corp., McLean, VA. This undertaking is constructing advanced query capabilities, including geographic referencing such as "give me all the data points in a data set that were collected over Eastern Europe or within 80 km of the coast of Australia." This project and Sequoia 2000 are investigating the integration of data management across a database management system and archival storage.

The area of data management paradigms is undergoing an active surge of development. Traditional database management systems are based on the assumption that the data could be organized easily in a tabular form. This poses difficulties in dealing with complex scientific data. To facilitate the handling of these data, new paradigms are being developed and applied. A considerable number of groups, including one in NASA's Goddard Space Flight Center, are experimenting with the application of object-oriented methods to scientific data management. This technology is relatively new, however, and awaits an industrial-strength implementation.

The visualization of data and information is of crucial importance to the user interfacing with these data and information systems. New and effective methods for visualization of environmental data are being developed around the world, for example, at the IBM Watson Research Center, Jet Propulsion Laboratory, and The Mitre Corp.

In addition, pioneering work in extracting information from data and visualizing it has been done at Xerox Palo Alto Research Center. In this work, hierarchical information is animated and represented in three dimensions. —*N.G. and G.M.*

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Modeling the world's climate

Global warming and the hole in the ozone layer are among the problems tackled by simulations on supercomputers

Will global warming turn green fields into desert, tundras into fertile farmland? Will the hole in the atmosphere's ozone layer repair itself after chlorofluorocarbon emissions have ended? Will a volcanic eruption in Mexico stunt crop growth in Canada?

These are among the questions that climate modelers try to answer. They use numerical simulations to project variations in climate for one year, or a decade, or several hundred years. The calculations are complex and require massive computing power to address—even today's supercomputers, capable of billions of floating-point operations per second, leave researchers frustrated at the crudity of their tools.

At the core of today's simulations of future climates are the General Circulation Models (GCMs) in use at laboratories around the world [Fig. 1]. Each model divides the atmosphere into layers and the earth into a grid along lines of latitude and longitude. For each three-dimensional grid cell, or grid point, a handful of equations must be solved, then solved again at regular, prescribed intervals, or time steps. Forcing factors, meaning external information such as the amount of solar radiation, the amounts of greenhouse gases like carbon dioxide, or the position of the earth, are used as inputs. From these basic models have evolved many GCMs that also predict changes in the chemical composition of the atmosphere, in the characteristics of the oceans and sea ice, and in other features of the earth.

A typical GCM today uses some 50 000 lines of Fortran code. Its grid cells are 4½ degrees latitude and 7½ degrees longitude (450 by 750 km), with time steps of 30 minutes. The atmospheric layers reach 30 km into the stratosphere and number at least 10, varying in depth from several meters to several kilometers. (By contrast, mesoscale modeling, which includes weather forecasting, requires much greater resolutions—10-by-10- to 50-by-50-km boxes—and therefore is performed on a regional basis.)

Tekla S. Perry Senior Editor

For a GCM, approximately 150 000 equations must be solved for each time step, requiring the equivalent of 10 hours of processing by a single Cray Y-MP processor for every year of climate simulated. A hundred-year simulation—not uncommon for a study of global warming—thus takes 1000 Cray Y-MP hours.

The time intervals needed to make the model work accurately must be shortened as resolution is increased. Researchers would like to shrink the grid spacing since, at 500 km, the Rocky Mountains are barely distinguishable from the Sierras; but computing requirements are prohibitive.

"If you are going to look at how global warming will affect the Great Basin Butterflies [in the Western United States]," said Stephen Schneider, a climate modeler and biology professor at Stanford University in Palo Alto, CA, it would require a minimum of 50-by-50-km resolution and 20 atmosphere layers stretching 50 km high, and "would take two years of Cray Y-MP time to simulate one year of climate. We are not going to get there any time soon."

> No one knows if 'the leap to parallel processing is into a cold muddy hole or a wonderful new body of water'

FIRST FORECAST. Climate modeling has had a long gestation, as has its sister science, numerical forecasting of the weather in terms of temperatures, winds, and precipitation. Most of the basic formulae derive from Newton's laws, and a simple climate model can be created from just a few equations: the second law of motion; conservation of mass; the first law of thermodynamics; a state equation relating the pressure, density, and temperature of the atmosphere; a state equation relating the temperature, density, and salinity of the oceans; and an equation for the conservation of mass of water.

These equations were first used to model the atmosphere in the 1920s by a British scientist, Lewis F. Richardson. He took a set of difference equations—approximations of the differential equations representing aspects of atmospheric change—and developed "computing forms" to solve them for different locations on the globe. His intent was predicting weather. He envisioned a large amphitheater representing the world, locations around the hall representing different geographic regions, individuals at each location busily performing calculations, and messengers running between them.

Richardson never built his amphitheater, but he did attempt a numerical forecast by solving his equations by hand. Unfortunately, the results were gibberish, due, say researchers today, to a simple error—the choice of a time step out of proportion to the size of his grid boxes, so that a numerical instability "blew up" the calculations.

ENTER COMPUTERS. A sort of "computing amphitheater" came into existence in the 1950s, with the birth of the Eniac at Princeton University in New Jersey. A weather simulation was one of the first major problems run on this early computer, and ever since then climate and weather modeling have been among the first applications transported to the "supercomputer" of each era.

The complexity and power of weather models grew in step with the available computing. A primitive climate model was developed in 1956. Norman Phillips, then a researcher at the Institute for Advanced Study, in Princeton, NJ, produced a simulation with a simple temperature pattern that, when computed out several months, generated "storms" and other weather phenomena.

In the early 1960s, the first full-scale GCMs were developed. One came under the National Oceanic and Atmospheric Administration (NOAA), at its Geophysical Fluid Dynamics Laboratory at Princeton University. Others were at the University of California in Los Angeles and at the National Center for Atmospheric Research (NCAR) in Boulder, CO [Fig. 2].

Today, there are well over two dozen of these general circulation models in the world, including those at the European Centre for Medium Range Weather Forecasts in Reading, England, at Météo-

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France in Toulouse, at the Commonwealth Scientific and Industrial Research Organization near Canberra, Australia, and at the Canadian Climate Center in Downsview, ON. An estimated 1000 researchers spend their days modeling various aspects of climate.

The early climate models ran on IBM punched-card computers. It took about one day of computing to simulate one day of atmospheric activity at a resolution of approximately 5 by 5 degrees with a few vertical levels. At the Boulder research center, CDC 6600s sped up the simulations to one hour per day and allowed more complexity; the CDC 7600 in 1972 managed 12 minutes per day. Other centers followed similar upgrade paths.

In the mid-1970s, the Cray 1, the first vector supercomputer, made calculations four times as fast as the 7600 and, because of its vector-processing capability, speeded up the existing GCMs to about 2 minutes per day simulated. This led to a change in the way these weather models were used.

Until the advent of the Cray 1, the models at the Boulder center and elsewhere had been run in what was called "perpetual January" mode. To keep the models from becoming too complex and increasing computing time, the January values for the earth's position in relation to the sun, the oceans' temperatures, soil moisture, ozone levels, carbon dioxide levels, and other factors were entered as constants, and the only variations were from one January to the next. With the Cray 1, and a speed of 2 minutes per day of activity at the existing GCM resolution, researchers finally could flee the depths of winter and look at year-round climate.

Robert Chervin, a research scientist in the Boulder center's climate and global dynamics division, was one of the first to break out of January mode. "The first experiment I attempted was a 20-year integration, which took over 200 hours of machine time, and because of computer allocation issues and hardware problems, it took eight calendar months to complete," he said. "The good news was that it was faster than real time, the bad news was that I aged considerably in the process."

Chervin said it was this experience, as well as the need to model the oceans, refine model resolution, and do other necessary tasks, that in the early 1980s drew him into the nascent field of parallel supercomputers. "I have devoted a fair amount of time to figuring out how to do these computations in parallel in order to reduce the mean time to publication," he told *IEEE Spectrum*. "I'm insane enough to tackle these big problems, but I'd like to get them over with as fast as possible."

PARALLEL PROMISE. The workhorse computers of today's climate modelers are the eight-processor Cray Y-MP, which has a peak speed of 2.6 gigaflops and runs at approximately 1 gigaflops when calculating climate models, and the 16-processor C90, which can run climate models about five times faster. Their speeds have taken modelers far. At the NOAA lab in Princeton, for example, a coupled atmosphere/ocean/sea ice model is being run with 400-kilometer-square resolution (typical by today's standards, though still coarse), 9 layers in the atmosphere, and 12 layers in the ocean, and takes 12.6 processor hours per year, said laboratory director Jerry Mahlman. So far, it has been run to 500 years in a number of experiments.

But the gains in speed of individual vector processors have begun to plateau, and climate modelers are hoping advances in massively parallel architectures will yield the computing power they need to reduce the wall-clock time (as opposed to processor time) it takes to run climate models. They then could make their models more complex and more accurate. They have some doubts, however. Said Stanford's Schneider: "The jury is still out as to whether the leap to parallel processing is into a cold muddy hole or a wonderful new body of water."

"People who are trying to get realistic models working on such computers are finding enormous frustrations," said Warren Washington, director of the Boulder center's climate and global dynamics division and a member of President Bill Clinton's transition team. "We can do it, we have demonstrated it, but it doesn't give the hoped-for speed-up." He indicated that researchers continue to hope that a maturing technology and better operating systems and tools will significantly increase computing speed.

At the Lawrence Livermore National Laboratory in Livermore, CA, physicist William Dannevik said, "Our focus now is getting our global model to run on massively parallel computers. I think there is a virtual certainty that this will have a big impact," even though today, he said, the 16-processor Cray C90 is still beating the best massively parallel machines.

"This is a risky business," Michael Schlesinger, professor of meteorology at the University of Illinois in Urbana-Champaign, told *Spectrum*. "It was easy to move to subsequent generations of Crays, but there is more than one massively parallel architecture, and it could turn out that the time we invest in moving to one machine is wasted if the next generation is not compatible."

So far no one has worked much on massively parallel systems, and only a few models have been ported to them. June delivery dates were scheduled for the Boulder center to receive its Thinking Machines CM5 and for NOAA to receive an Intel Paragon. The porting effort is not trivial; each model takes several person-years to recode for each parallel architecture, and researchers, typically working in small groups, are reluctant to invest the time when the fruits are uncertain.

NOAA's Princeton laboratory is developing modular forms for simpler parallel coding of its atmospheric and ocean models on a 1000-node CM5 at Los Alamos. Researchers at the Livermore lab are also in the process of writing a model with portable source code. Others at the University of Illinois are currently converting their GCM to a 512-node CM5.

At the Boulder center, Bill Buzbee, director of its scientific computing division, said that he expected it would require two person-years to convert the center's general circulation model to the organization's new CM5. The same model is being converted to the Intel Paragon.

Several government-sponsored initiatives

Defining terms

External forcing factor: a circumstance that alters, but is not itself altered by, the state of the climate; examples are solar radiation and the carbon dioxide emitted by burning fossil fuels.

General Circulation Model (GCM): a method of modeling the earth's climate based on a set of fundamental equations, including the second law of motion; the law of conservation of mass; the first law of thermodynamics; a state equation relating the pressure, density, and temperature of the atmosphere; another relating the temperature, density, and salinity of the oceans; and a moisture equation. The method involves dividing the atmosphere up into a series of three-dimensional boxes, and then solving these equations for each box.

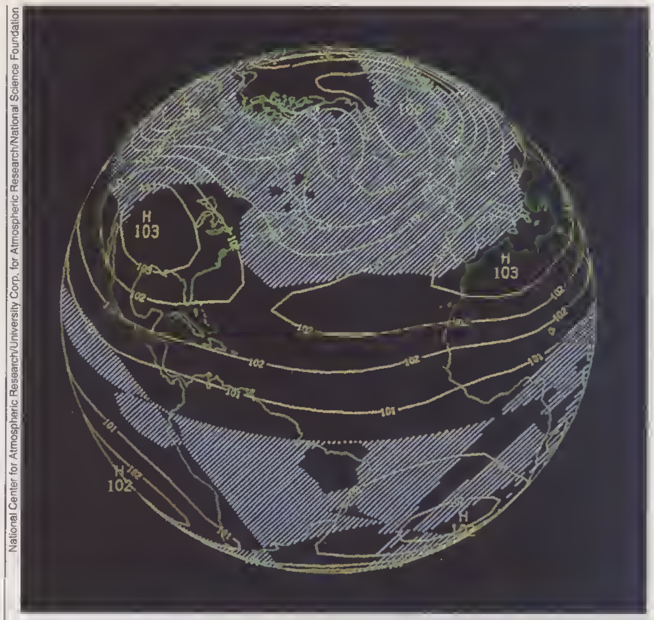
Grid cell or grid point: interchangeable terms for the basic unit of a GCM. A typical grid cell is delineated by so many degrees latitude and longitude and from several meters to kilometers in height. A grid point represents the average for each cell.

Massively parallel supercomputer: a computer architecture in which multiple linked processors act on a problem simultaneously. Such systems today may have as many as 1000 processors.

Numerical forecasting: a method of predicting climate or weather by solving a set of basic equations. One type of climate forecast relies on the GCM [see above]. Numerical weather forecasts extrapolate from an initial state and try to track its evolution in detail. They typically cover smaller regions at higher resolutions.

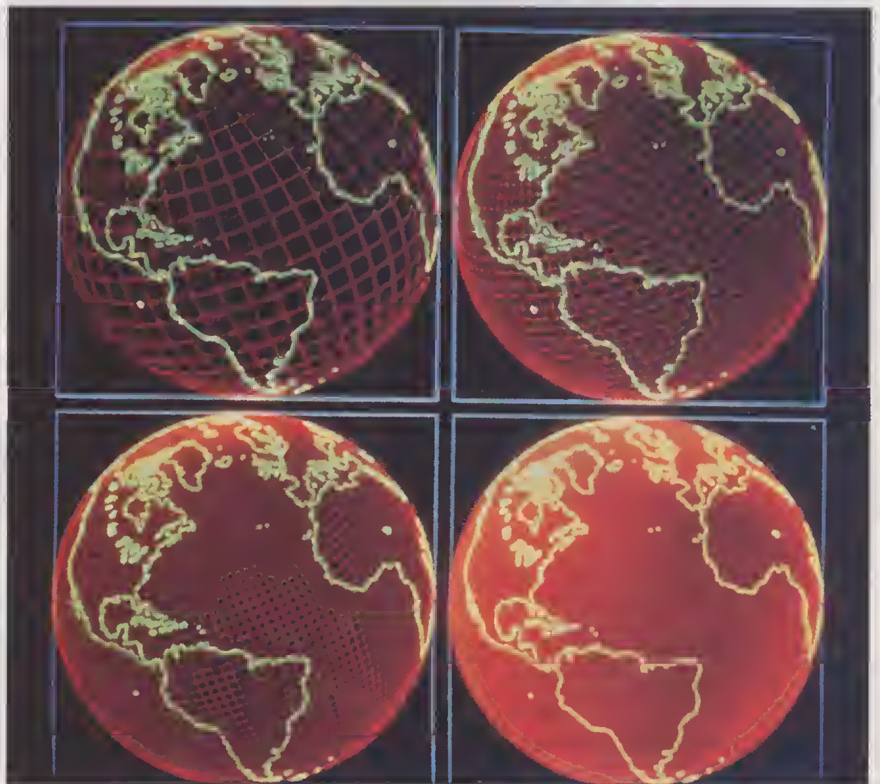
Parameterization (or parametric representation): the derivation of weather or climatic phenomena that are smaller than a model's scale of resolution (cell size) from phenomena that are resolved by the model. For example, cloudiness can be derived from grid-cell averaged values of temperature, winds, and humidity, and that derivation used to adjust atmospheric temperature.

Time step: in numerical forecasts, the preset interval at which the set of calculations for each grid cell is performed—30 minutes for a typical General Circulation Model. As grid resolution increases, the time steps must decrease proportionally, or an instability in the calculations will occur and cause errors.



National Center for Atmospheric Research/University Corp. for Atmospheric Research/National Science Foundation

[1] General Circulation Models (GCMs) track a number of the components of climate. The image at left, generated from a GCM, shows cloudiness and sea level pressure. Those below show four possible resolutions for GCMs: the 8-degree (latitude and longitude) grid [top left] is used for climate research; the 4-degree grid [top right], for experimental weather forecasting; the 3-degree grid [bottom left], for U.S. weather forecasts; and the 1-degree grid, comparable to that used for European forecasts.



support moving climate models to more advanced computing platforms. The High Performance Computing and Communication (HPCC) initiative aims to "accelerate the development of a thousand-fold improvement in useful computing capability and a hundredfold improvement in available communication by 1996 and... enhance the range of scientific and engineering disciplines that can effectively exploit this computational capacity," according to a report by the Office of Science and Technology Policy. Climate modeling is one of the disciplines at the top of the initiative's list. The HPCC is funded by a number of agencies, including the (formerly Defense) Advanced Research Projects Agency, the National Science Foundation, the Department of Energy, the National Atmospheric and Space Administration, the Environmental Protection Agency, and NOAA.

Another program, the Computer Hardware, Advanced Mathematics, and Model Physics (Chammp) Climate Program, is funded by the Department of Energy. Its focus is integrating improved modeling methods with next-generation high-performance computing systems, which these days largely means parallel systems. The goal is increased speed and accuracy for climate model simulations.

While increasing parallelism is one step toward enhancing climate models, another development may have equal potential: the proposed electronic superhighway, the high-speed national data network. Although climate researchers today use remote supercomputers a fair amount, the effectiveness of this approach is limited by the narrowness of the bandwidth of available communications and the large storage requirements of climate models.

"To make valid comparisons between one simulation and another, we have to store the resulting data in sufficient density in space and time," Buzbee said. His center has 30 terabytes of data storage. "In addition, you need observational data to calibrate the models—we have 3 terabytes to date." Scientists today pull out small segments of such data for analysis; with a high-speed national network they could move the entire output of a simulation from place to place, for comparison with other simulations or observations.

Researchers are also looking into distributing computation on supercomputers linked by a high-speed network. Trials are being performed by Cray Y-MPs at the Boulder center and at the Ohio Supercomputer Center in Columbus.

WORKSTATION WONDERS. At almost the other end of the computer spectrum, some researchers are discovering that for certain simulations, workstations, preferably multiple workstations, are their best bet.

Workstations—and even lower-power personal computers—have long performed one type of climate simulation: the energy balance model. With this method, factors that affect climate, like the amount of solar radiation entering and leaving the atmosphere or the carbon dioxide content, are aggregated over large areas, like an entire latitude, and calculations are made inferentially. For example, the quantity of heat transported by the winds is calculated from the temperature difference between the equator and the pole or between the land and the sea. Winds, therefore, are not explicitly computed using vast amounts of computing power.

These simple models can still provide useful information, for example, on the increases in the land or ocean surface temperatures over the next 100 years when nonfossil and fossil fuels are used. Hundreds of thousands of years of simplified climate can be simulated without overtaxing computer resources.

At NASA's Goddard Institute for Space Studies in New York City, director James Hansen and his colleagues have developed a low-resolution GCM—8 degrees latitude by 10 degrees longitude (approximately 1000-kilometer-square boxes) and 9 vertical layers ranging in height from about 400 meters near the ground to several kilometers in the stratosphere. This model runs on IBM and Silicon Graphics workstations based on reduced–instruction-set computing (RISC). One day of processing yields

five years of simulated climate changes.

Hansen's group has simplified the model even further by using an artificial geography that runs three times as fast. Models with such coarse resolutions are not designed to look at climates in specific regions, but they can be run fast and often, and therefore can study climatic issues much farther into the future than traditional GCMs. The researchers at Goddard have run their models out to 3000 years so far.

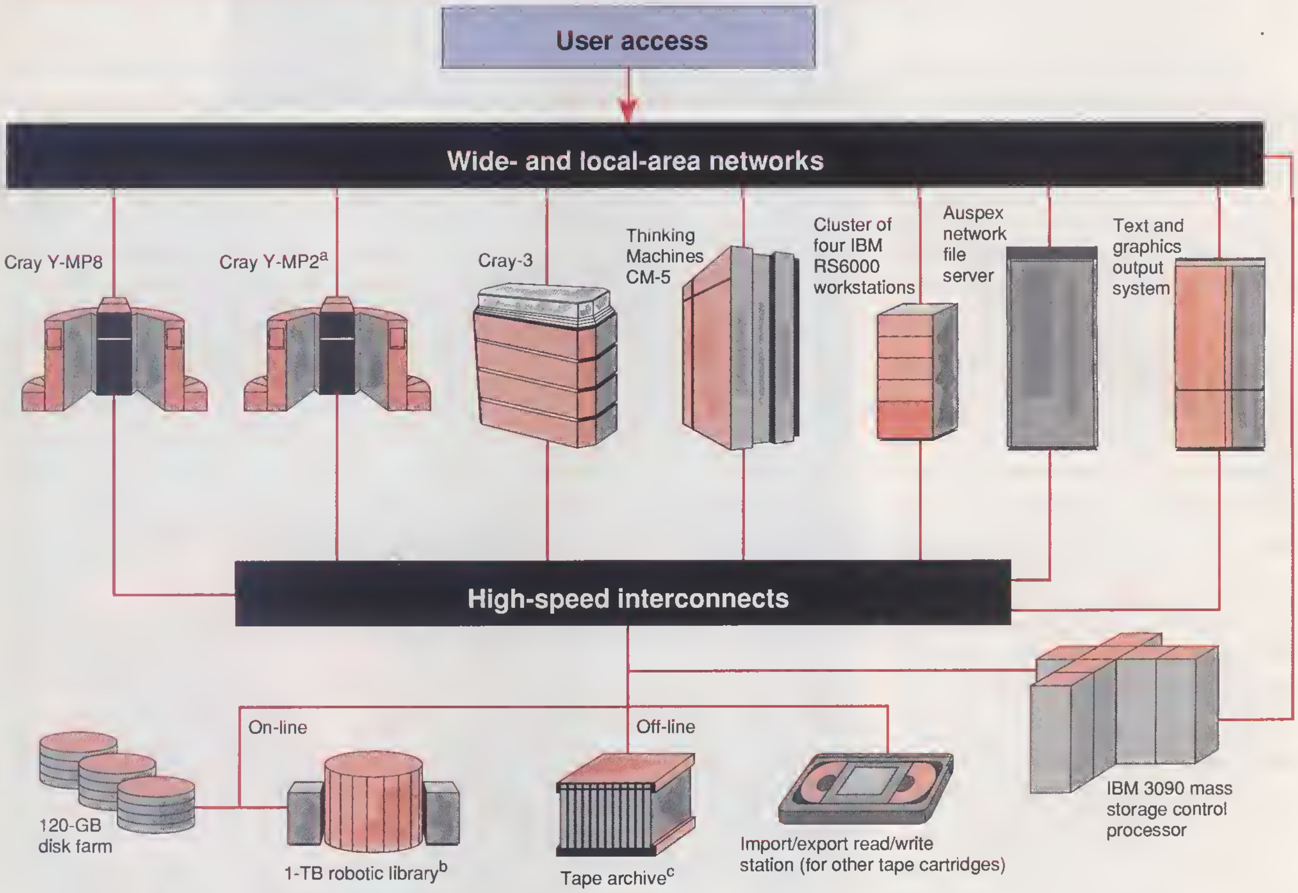
Workstations can also study individual features of a climate. For example, at Harvard University, Cambridge, MA, associate professor of atmospheric chemistry Daniel Jacob is modeling the elimination of pollutants by oxidation on RISC workstations. Their vendors include IBM, Silicon Graphics, and Digital Equipment. When Jacob simulates North America at a resolution of 4 degrees latitude by 5 degrees longitude and 9 atmospheric layers, with local subgrids to highlight pollutant plumes, he can look at six types of chemical reactions over three months of atmosphere in a computer run that takes one-half hour.

Thus, modelers can call on a wide range of computing platforms to make a number of useful and fairly confident predictions about weather and climate.

WEATHER. Numerical weather forecasting differs from climate modeling in that it truly seeks to provide deterministic, detailed forecasts, as opposed to statistical predictions. It foretells sunshine or rain at a specific time and place, not whether the chance of an abnormally dry or wet summer has increased by 10 or 20 percent.

To pinpoint thunderstorms, local weather forecasting requires models with much more detail and higher resolution—grid spaces 10 to 20 kilometers square. Lower-resolution models can predict winds and temperatures, though not precipitation in the case of small storms. Because of the need for high resolution, weather models are run on a regional basis, sometimes with small high-resolution areas nested in larger lower-resolution ones. A February 1992 simulation called Stormfest used nested resolutions to test experimental models of the

Computing resources at the National Center for Atmospheric Research



a The Cray Y-MP2 is supported by the Model Evaluation Consortium for Climate Assessment (Mecca).
b Holds 6000 tape cartridges, each holding 200 MB.
c Holds 100 000 tape cartridges, each holding 400 MB.

Source: National Center for Atmospheric Research, Scientific Computing Divisions

[2] Extensive computing power is required to run today's General Circulation Models. On the ground floor of the National Center for Atmospheric Research, in a building that looks like stacks of futuristic blocks (and was used as the laboratory building in Woody Allen's 1960s movie, Sleeper*) is one of the many massive computing facilities that tackles climate research. The most recent arrivals: the first gallium arsenide–based Cray 3 supercomputer to leave the Cray Computer Co.'s laboratories and the Thinking Machines CM5 massively parallel system.*

The second, two-processor Cray Y-MP shown is the only supercomputer in North America totally dedicated to large-scale simulations of climate. It is provided by the Model Evaluation Consortium for Climate Assessment (Mecca), sponsored by the Palo Alto, CA, Electric Power Research Institute and a variety of international power organizations. Established in 1991 with the goal of assessing the reliability of climate models, Mecca will continue to make the Cray Y-MP available to a select group of researchers through the end of this year and possibly into 1994, depending on funding.

The center's mass storage is substantial. The 1-terabyte robotic library holds six thousand 200-MB tape cartridges and has 12 read/write stations. Active files are kept here. The larger library, operated manually, holds a hundred thousand 400-MB cartridges, and files are loaded into a bank of read/write stations when requested. No backup files are kept; instead, the storage systems are carefully controlled. In six years of operation, this system has failed to read only seven files.

The text and graphics output system consists of printers (laser and photographic), videotape systems, and, for visualization, Sun Microsystems and Silicon Graphics workstations. Each day the system outputs approximately 5000 laser pages, 3000 frames of 35 mm film, and three videotapes, each several minutes long.

weather over the central United States. For one month these models made two-day forecasts, every day, running for one and one-half hours on six of a Cray Y-MP's eight processors [Fig. 3].

As the high-resolution mesoscale models currently being developed move into operational weather forecasting, "expect 24-hour forecasts, especially of precipitation, to become impressive," said Robert Gall, director of the Boulder center's mesoscale and microscale division. Three-day forecasts are also becoming quite reliable, Gall said, and today's 10-day forecast is as accurate as a three-day forecast was 10 years ago, thanks to increases in computing power.

"The remarkable thing about the recent 'Storm of the Century'," Gall said, "was not just its weather, but also the fact that its intensity, basic track, and extent of snowfall were forecast two days ahead."

Today's weather forecasts can see out, with some accuracy, as far as 10 days. Researchers are trying to push that envelope, said David Rodenhuis, director of NOAA's Climate Analysis Center in Camp Springs, MD. But most agree that two weeks is the limit because of the instability inherent in the earth's oceans and atmosphere. Small disturbances, after some time, cause large divergences in weather. Beyond two weeks, the question becomes one of statistical probability, and crosses into the field of climate modeling.

GLOBAL WARMING. Perhaps one of the most far-reaching questions that climate modelers today are addressing is the greenhouse effect and its influence on global warming. The greenhouse effect is the tendency of certain gases in the atmosphere, notably carbon dioxide, to trap heat below them in the same way that glass traps heat in a greenhouse. This is a key question because it could dramatically affect environment and society, and be dramatically affected by government policies, and because it is, from the modelers' perspective, almost basic science. The study of global warming does, after all, require improvements in knowledge about the atmosphere, the oceans, the biosphere, and the earth and improvements in how this understanding is factored into models.

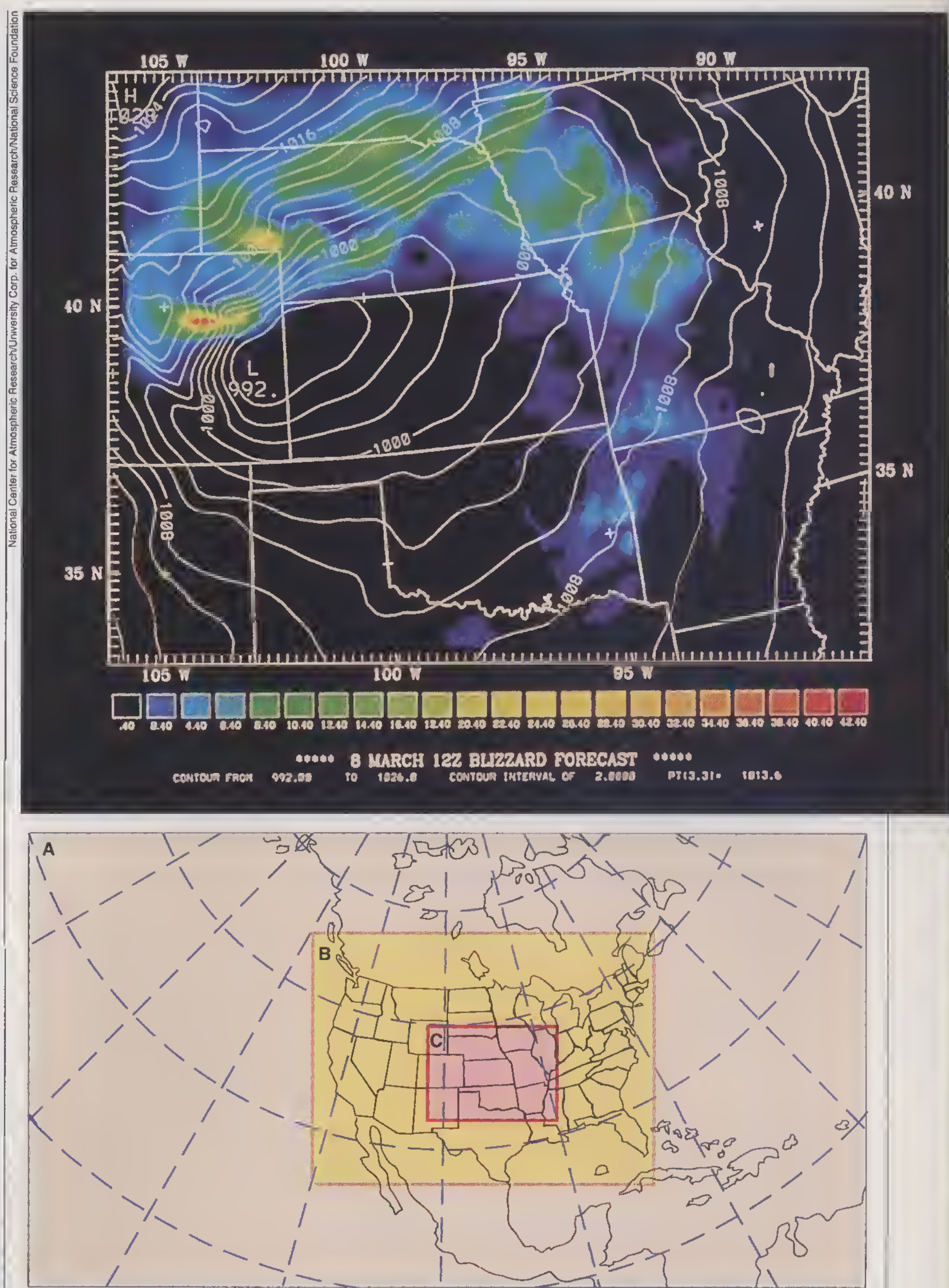
In the early 1970s, modelers at NOAA's Princeton Laboratory ran the first general circulation model to incorporate rising carbon dioxide levels. Today, researchers worldwide are studying global warming. Basically, they run a general model that incorporates the greenhouse gases—carbon dioxide, methane, water vapor, Freons—for some period of time while the carbon dioxide in the atmosphere remains at current levels; then they run another model that gradually increases those levels in various scenarios; finally they compare the results.

Researchers at the Boulder center have repeatedly run their greenhouse model to 100 years [Fig. 4]. The Princeton lab recently ran a greenhouse simulation to 500 years three times: once with carbon dioxide steadily increasing to double the present level, once with existing carbon dioxide emissions, and once with steadily increasing carbon dioxide to four times the current level. The results, said Mahlman, are surprising but have yet to be announced.

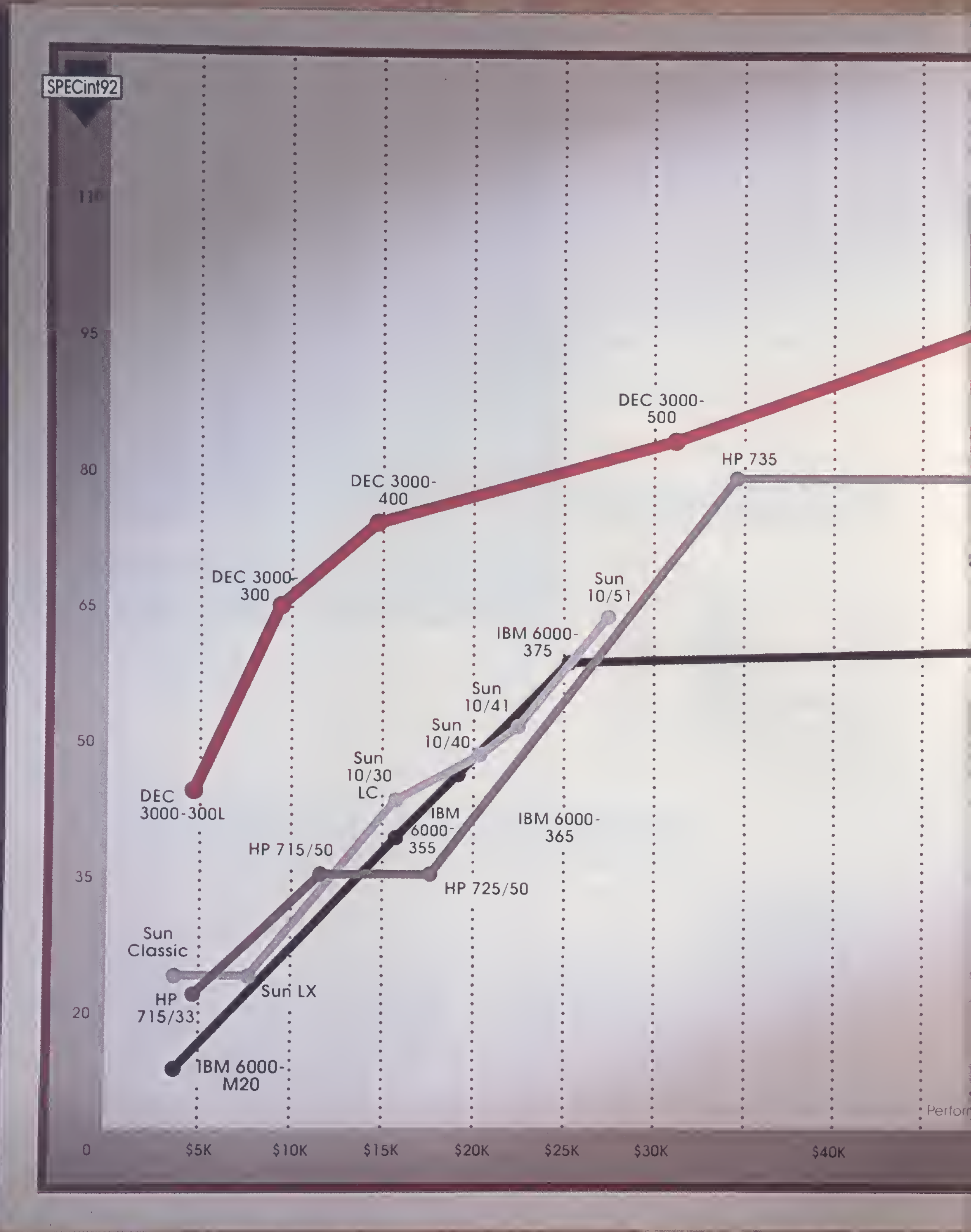
Combining results of the various models so far leads to these conclusions, according to Boulder center director Washington: given our present rate of burning fossil fuels, which will lead to a doubling of atmospheric carbon dioxide in 30–60 years, average earth temperatures will rise between 1½ and 4½ °C in the next 50–100 years. There will be more rain in the tropics and less in the subtropics, for example, and North America and Asia would have warmer winters and drier summers, which would hurt agriculture. Monsoons in Asia would be a little worse than they have been in the past, if the model projections are valid.

The details of this warming at the regional level are a subject of much speculation. What would be the effect of global warming on the Great Lakes? Would Europe get warmer, or even colder for a few decades before heating up? Would higher temperatures in China be coupled with increased rainfall and therefore improve crop yields? Would the birds relocate?

National Center for Atmospheric Research/University Corp. for Atmospheric Research/National Science Foundation



[3] A February 1992 experiment called Stormfest tested weather models over the central United States. The experiment used nested resolutions [bottom, from out to in] of 180 km, 60 km, and 20 km and tracked various components of the weather. The computer-generated image [top] shows winds and temperatures for the innermost resolution.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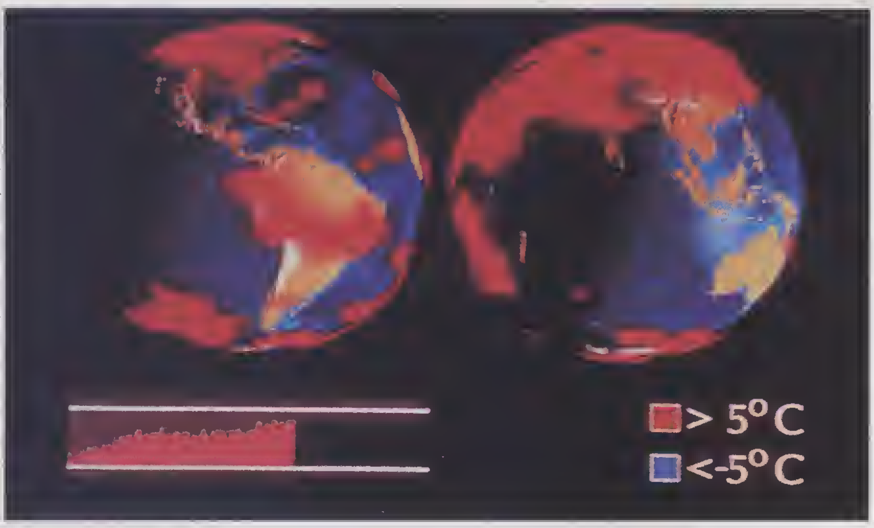


[4] This image from a climate model shows global warming 12 years after simulated carbon-dioxide levels have grown to double what they are today. The red areas indicate a temperature increase of 5 °C or more; the graph shows the warming trend.

For answers, not only would the resolution of the models have to increase, but as (or more) important, models of the atmosphere need to be coupled to models of other earth systems, the oceans, the soils, large lakes and rivers, forests and grasslands, and so on. Today's biggest efforts focus in on such coupling.

The oceans, with their ability to store, move, and release heat, are a major influence on climate. For example, the Gulf Stream brings warm water up the East Coast of North America from the tropics, then veers east and heads for the British Isles. As a result, Britain is much warmer than Canada at corresponding latitudes. Global warming, for various reasons, could slow down the Gulf Stream, and London could find itself in a cold snap amid a warming world.

Since 1969 researchers have run coupled atmosphere and ocean models, using either a coarse resolution or prescribing unvarying temperatures for the oceans. Today's coupled models use at best a few degrees latitude and longitude for ocean resolutions. These resolutions fail to capture important oceanic features, because the scales at which currents and accompanying temperatures—the eddies—move are a hundredth of those in the atmosphere.

Chervin and collaborator Albert Semtner, oceanography professor at the Naval Postgraduate School in Monterey, CA, have produced a world ocean model with ½-by-½-degree resolution and 20 levels of ocean varying from 25 meters to several hundred in depth [Fig. 5]. (The two recently won the Cray Research Award for Breakthrough Computational Science for their work.) "At that," Chervin said, "we are at the margin of eddy resolvability."

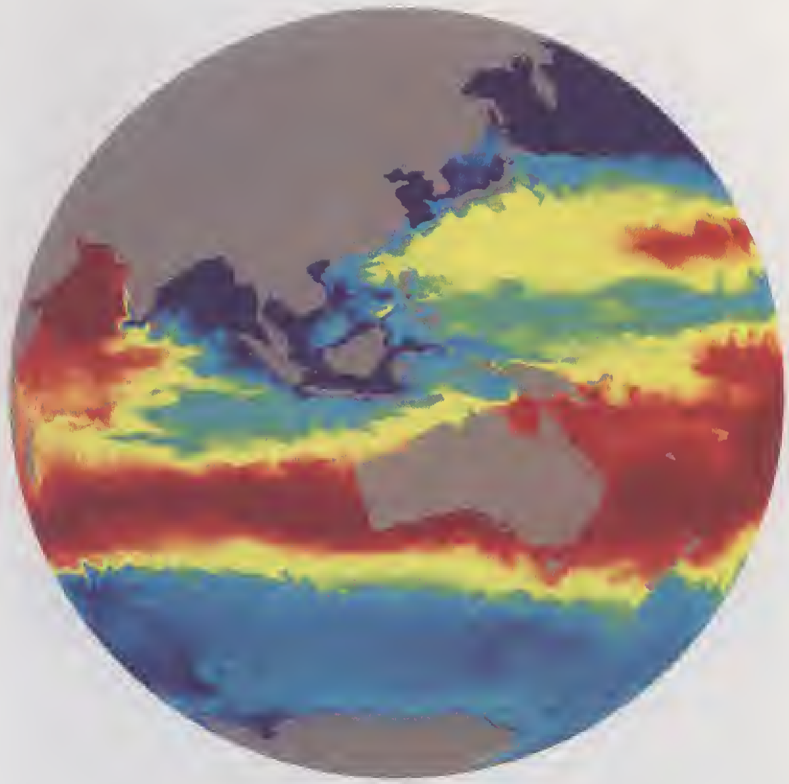
Other climate researchers have also resolved ocean eddies in their models, which, however, do not cover as much of the globe as the Chervin and Semtner model. The Fine Resolution Antarctic Model at Oxford University does so for the southern one-third of the world's oceans. A model developed cooperatively by researchers in the United States and Germany, called the Community Modeling Effort, is simulating eddies in the North Atlantic at a resolution of ⅓ degree square.

This Chervin and Semtner model, with its four million grid points, takes 27 wall-clock hours to simulate one year on a dedicated eight-processor Cray Y-MP. But because the ocean changes more slowly than the atmosphere, longer time periods are needed to track phenomena. Chervin and Semtner would like to model hundreds, or thousands, of years—100 years would take 900 processor days to run. The computer demands that would be made by coupling this high-resolution model to a GCM would be prohibitive, so today's coupled atmosphere-and-ocean models use much lower resolutions and try to parameterize eddies.

"It would be very nice if we could run atmosphere/ocean models with resolutions like Chervin and Semtner," Washington told *Spectrum* in Boulder, "but if we do, we cannot carry out experiments in our lifetime, so we have to compromise."

Researchers would like to couple other earth systems with GCMs. Topography, ground and surface water hydrology, terrestrial ecosystems, marine biochemistry, and detailed atmospheric chemistry are all being modeled separately today and could, if coupled with today's GCMs, improve them greatly. But until computing speed increases by factors of 100 or 1000, such coupling will remain impractical. In the meantime, scientists are using simple, parameterized models and factoring those into GCMs.

One parameterization effort surrounds clouds. Scientists are trying to understand



[5] Oceans, with their ability to store, move, and release heat, are an important influence on climate. This recently improved global model has a grid spacing of 1/4 degree latitude and longitude—fine enough to track the ocean eddies, which have long eluded researchers. The model was developed by Albert Semtner of the Naval Postgraduate School and Robert Chervin of the National Center for Atmospheric Research.

how they are formed; modelers are using this information as it develops to get their models to create average cloud cover (the resolution is far too coarse to describe individual cloud formations), how it is changed by different scenarios, and how it in turn changes climate.

Clouds are the biggest determinant of climate, said Stanford's Schneider, "and who has ever seen a cloud the size of Colorado?" He has been working on methods to parameterize clouds; to determine what factors, to what extent, increase or decrease cloud cover; and to include those formulas in atmospheric models.

"We are unsure now whether clouds will change to amplify greenhouse warming or to damp it," said Mahlman of the NOAA Princeton laboratory. This uncertainty is behind the large spread in global warming predictions.

Clouds may be "seeded" by aerosols, tiny particles dispersed in the atmosphere, which are therefore also the subject of some attention.

According to Dannevik at Livermore, some studies have suggested that the sulfate aerosols produced by some fossil fuels cool the atmosphere, mitigating greenhouse warming. (On the other hand, sulfate aerosols are not benign—they lead to sulfuric acid deposition, or acid rain.) As aerosols are shorter lived than greenhouse gases, reducing the use of fossil fuels, in the short term, could exacerbate global warming.

DECREASING OZONE. The most imminent climatic threat is the depletion of the ozone layer. Modelers first began to study it intensively in the early 1970s, when the supersonic transport plane was proposed and it was feared that the exhaust emissions from a fleet of such planes might harm the ozone layer. The modelers concluded it would, but they also determined that other activities, most notably the release of chlorofluorocarbons (CFCs), could also deplete the ozone layer.

Until recently, the models that studied the ozone layer were run separately from GCMs and represented the atmosphere in terms of height and latitude or just height.

"Nobody dared to do chemistry on 3-D models at that time because it would have been prohibitively expensive," said Rolando Garcia, senior scientist in NCAR's atmospheric chemistry division. The 70-some chemical reactions that must be tracked for each point increase the computing demands exponentially. Even now, Garcia said, it is at the limit of present computers.

A three-dimensional model with realistic stratospheric chemistry and spatial resolution of 5 degrees latitude and longitude and 2-km vertical resolution takes about five Cray Y-MP hours per month of simulation. A model of the recovery of the ozone if CFCs are banned might need to be run out to 70 years, which is still prohibitive in a 3-D model. So Garcia and company work in two dimensions and use some sort of parameterization to represent how the ozone is affected by the wave motion of the atmosphere.

The ozone layer is involved in the greenhouse effect. This involvement, because of its complexity, is only beginning to be modeled. The University of Illinois this summer was to begin the first experiments with a 24-layer model that includes ozone chemistry. Its seven-layer version of that model required 108 seconds of C90 processor time to compute one day.

'The world is gearing up to change lifestyles radically based on these predictions. What if we are radically wrong?'

Ozone models recently underwent a validation test, in the guise of the 1991 volcanic eruption of Mount Pinatubo in the Philippines. According to Garcia, after Mexico's El Chichón erupted in 1982, unexpected ozone depletions occurred. One theory, written into some models, was that volcanic particles created droplets of sulfuric acid that catalyzed ozone-eating chemical reactions in the atmosphere. Now, two years after Mount Pinatubo's eruption, scientists are measuring ozone depletion that occurred as anticipated by this model.

DECISION-MAKING. Researchers expect to be investigating a number of climate questions for years to come, and without reaching conclusive answers. Even so, many think that the time for governments to take action on these issues is now.

The mechanisms by which CFCs deplete the ozone, and how fast the ozone will recover after CFC use is eliminated, are fairly well understood. "We had a theory; it worked when modeled numerically; it led to predictions which could be tested independently; and the tests confirmed the predictions," NCAR's Garcia said. Observed data, combined with the work of modelers, contributed to the signing of the Montreal protocol in 1987, an international agreement on a timetable for the phase-out of CFCs. Other questions have less well-confirmed answers.

Harvard's Jacob is focusing his current oxidation studies on hydrochlorofluorocarbons (HCFCs), which are replacing CFCs in numerous manufacturing processes. HCFCs do not deplete the ozone layer because they are quickly oxidized; the question is whether there is a limit to the amount that can be oxidized, and if so whether HCFCs will then prove just as destructive of the ozone layer as their sister compound.

"We have to talk to policy-makers regarding that issue," Jacob said, "and we don't yet know what to say."

At Carnegie Mellon University in Pittsburgh, an associate professor of mechanical engineering, Armistead G. Russell, simulates regions as large as the northeastern United States with a resolution that can be set as fine as 2 by 2 km, with up to 20 vertical layers ranging from 10 meters to several kilometers high, and with numerous chemical reactions. Russell's specialty is smog and whether it is more effective to control the carbon-based or the nitrogen emissions that interreact to create the ground-level ozone that damages the lungs.

Russell also studies the impact of alternative fuels on air quality. His group is working with the California Air Resources Board in Sacramento on how to treat the various fuels in writing regulations designed to improve air quality. But Russell, too, is yet undecided. "At this point we have the algorithms," he told *Spectrum*, "but they are very consumptive of computer power. Faster computers will make a difference."

Global warming is the most hotly debated issue, both because different models do not agree and because related policy decisions have broad societal impacts. Can the developed world demand that the underdeveloped world limit its development by not fully exploiting fossil fuel reserves? Are people in developed nations ready to give up their cars? Or to trust nuclear power?

There is some debate in the scientific community today about the role of the researcher in policy-making. If the researcher is not sure of his results, if finding a definitive answer could take years—what is his responsibility?

"We have made predictions about greenhouse gases and warming," said Schlesinger at the University of Illinois, "but we have yet to test those predictions, so we have no confidence. The world is gearing up to change lifestyles radically based on these predictions. What if we are radically wrong?"

Back in Boulder, Washington, who has advised every presidential administration since Carter's on environmental issues, is convinced of the wisdom of reducing the emissions of carbon dioxide and other greenhouse gases. While there are still "a lot of uncertainties as to the magnitude of the greenhouse problem, it is a fundamentally correct hypothesis—the problem is quantifying it," he told *Spectrum*. "If we wait, we may have harmed the environment irrevocably."

Said Stanford's Schneider: "You are talking about an experiment being performed on a laboratory called earth, and every living thing is along for the ride, whether they signed on or not. So it is our responsibility to make best guesses." ◆

To probe further

IN GENERAL. The *1993 EOS Reference Handbook* is available from the NASA Earth Science Support Office's Document Resource Facility by calling 202-479-0360 or writing to the address given below.

Space-Based Global Change Observation System Program Plan: An Assessment of Current Status and Interagency Cooperation was released last October; an updated version is due out next October. Contact George Schwenke at the Earth Science Support Office (address below).

Our Changing Planet: The FY 1993 U.S. Global Change Research Program may be obtained by calling 202-357-7861 or writing to the Committee on Earth and Environmental Sciences, Attn: Forms and Publications, c/o National Science Foundation, Room 232 (address below).

The Winter 1989 issue of *Mosaic*, published by the National Science Foundation (NSF), had a special report on "Detecting Climate Change." Write to Distribution, *Mosaic* (527), at the NSF address below or call 202-357-9498.

"Report to Congress on the Restructuring of the Earth Observing System" went to House and Senate appropriations committees in March 1992. Contact the NASA Earth Science Support Office, Document Resource Facility (address below).

Pergamon Press has a new catalog of its Environmental Science and Technology titles. Write to the press, either at Headington Hill Hall, Oxford OX3 0BW, UK, (44+865) 794 141, or at 660 White Plains Rd., Tarrytown, NY 10591-5153, 914-524-9200.

REMOTE SENSING. *Atmospheric Remote Sensing by Microwave Radiometry* is the new entry in the Wiley Series in Remote Sensing, from John Wiley, New York. The 572-page book was edited by Michael A. Janssen of the Jet Propulsion Laboratory.

The proceedings from a symposium on "Combined Optical-Microwave Earth and Atmosphere Sensing" are available from the IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331 (IEEE Catalog No. 93TH0519-9).

Monitoring Earth's Ocean, Land, and Atmosphere from Space—Sensors, Systems, and Applications was published eight years ago but has a great deal of valuable historical and technical information. The 830-page book was part of the Progress in Astronautics and Aeronautics series published by the American Institute of Aeronautics and Astronautics, 370 L'Enfant Promenade, S.W., Washington, DC 20024.

The "Joint Engineer-Scientist Workshop on Earth-Based Atmospheric Remote Sensing" was sponsored by the National Science Foundation and hosted by the National Center for Atmospheric Research in February 1992. For a copy of the proceedings, contact the NSF's Forms and Publications, Room 232 (address below) or call 202-357-7861.

"Submillimeter-Wavelength Heterodyne Spectroscopy and Remote Sensing of the Upper Atmosphere" was published in the *Proceedings of the IEEE*, November 1992, pp. 1679–1701. Experiments involving the University of Utah's polarization diversity lidar were described in "Evidence for Liquid-Phase Cirrus Cloud Formation from Volcanic Aerosols: Climatic Implications," *Science*, July 24, 1992, pp. 516–519.

A report on the Antarctic ozone hole was published in the April 15 issue of *Nature*. See "Stratospheric ClO and ozone from the Microwave Limb Sounder on the Upper Atmosphere Research Satellite," pp. 597–602.

The April issue of *Photonics Spectra*, published by Laurin Publishing of Berkshire Common, Pittsfield, MA, had a three-part report on "Photonics in Remote Sensing and the Environment." The magazine's telephone number is 413-499-0514.

DATA PROCESSING. *EOS Data and Information System (Eosdis),* which describes the system in some detail, was produced this past year by NASA's Earth Science Support Office and is available through its Document Resource Facility (address below).

For more information about the U.S. Global Change Research Program and related issues, see Helen M. Wood, "Understanding planet Earth: Challenges for CS/CE," *Computing Research News* (the journal of the Computing Research Association), Vol. 5, no. 3, May 1993, pp. 9–11.

A fuller description of Version 0 of Eosdis appears in S. C. Calvo and K. R. McDonald, "Accessing Distributed Heterogeneous Earth Science Inventories via Eosdis Version 0 Information Management System," *1993 ACSM/ASPRS Annual Convention Technical Papers,* Vol. 3, pp. 48-55.

Some of the issues concerning remote-sensing data management in the data and information systems of data are discussed in N. Gershon and J. Dozier, "The Difficulty with Data," *BYTE*, April 1993, pp. 143-147.

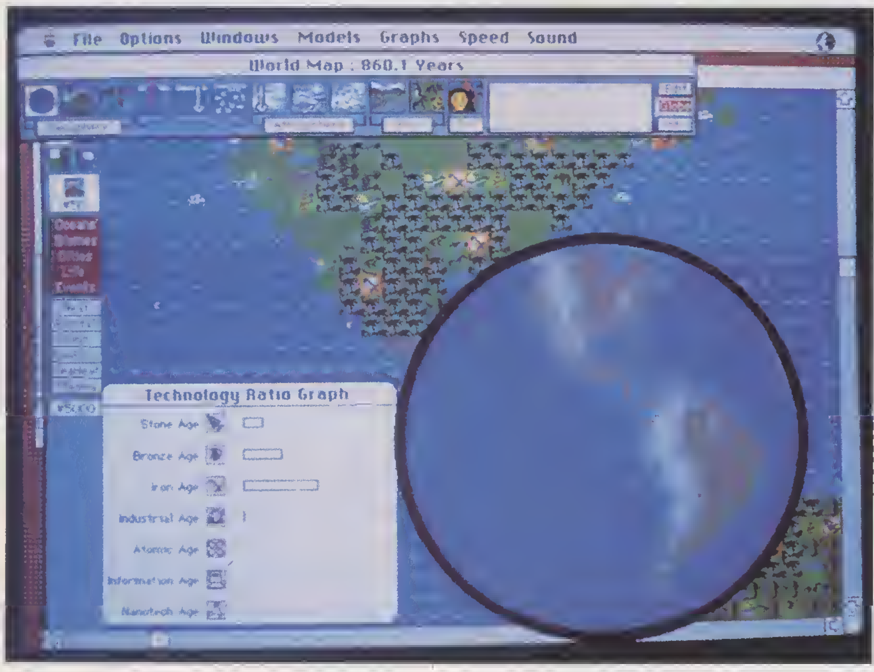
SUPERCOMPUTING. Discussions of the components of climate modeling and examples of equations used in General Circulation Models show up in a number of texts, including *An Introduction to Three-Dimensional Climate Modeling* by Warren M. Washington and Claire Parkinson (University Science Books, Mill Valley, CA, 1986) and *Climate System Modeling,* edited by Kevin E. Trenberth (Cambridge University Press, New York, 1992).

The National Center for Atmospheric Research, housed in a landmark building designed by I.M. Pei, offers free self-guided and guided tours of its facilities, including its computer rooms. The building, in Boulder, CO, is open from 8 a.m. to 5 p.m. and 9 a.m. to 3 p.m. on weekends and holidays.

Climate modeling is one of the Grand Challenge problems of supercomputing. The latest breakthroughs in this area will be discussed at Supercomputing '93, sponsored by the IEEE and the Association for Computing Machinery. This year's conference will be held Nov. 15–19 in Portland, OR.

ADDRESSES. The National Aeronautics and Space Administration's Earth Science Support Office is located at 300 D St., S.W., Suite 840, Washington, DC 20024.

The National Science Foundation is located at 1800 G St., N.W., Washington, DC 20550. ◆



Maxis Inc

SimEarth, the computer game, is not based on accurate mathematics, but does represent the Earth as a single organism, giving the player a sense of the interconnectedness of all the features of the geosphere, atmosphere, biosphere, and civilization, including such problems as global warming. Made by Maxis Inc., Orinda, CA, SimEarth is available for DOS and Windows for Macintosh and Amiga computers at most computer stores for under $50.

Running out of resources

As economic challenges confront the entire world, the IEEE has a unique opportunity to help on both local and global levels

Although many people reject the idea, humanity's future will be largely shaped by the zero-sum nature (at best) of the world economy. Since that economy is rooted in the continued exploitation of resources that are both finite and nonrenewable, any time one individual or group gets more of something, some other individual or group must necessarily get less: hence the term *zero sum.*

Supply-side economists scoff at this notion, maintaining that the economic pie can be made to grow indefinitely through human ingenuity and effort. According to them, everyone on earth can aspire to increasing material wealth and prosperity.

One reason that the zero-sum nature of the world economy is not evident to some skeptics is that the developed nations have gotten where they are by ignoring it—by exploiting cheaply available natural resources as if they were inexhaustible. Unfortunately, the developing nations will not be able to follow that example. As the cheap resources disappear, growth cannot continue in the same way, and the pie could shrink drastically—especially on a per capita basis.

Why is it appropriate to discuss this matter in the flagship publication of the IEEE? Because the Institute, through its constitution, has charged itself with a noble goal—namely, to promote understanding of the influence of technology on the public welfare of the entire world.

That goal has never been more apposite. It makes clear the proposition that the Institute's view of the implications of technology, as well as its benefits, cannot be confined to a narrow scope based on any country's national interest, but must represent the IEEE global constituency.

DISTURBING EVIDENCE. Of all nations, the United States is probably the most competent at wresting economic gain from the environment. Yet, even here, the timber industry is dying as the prime old-growth forests are running out and raw logs are exported to be milled overseas; the fishing industry on both East and West coasts has been devastated by dredge-net fleets from around the world; and farmlands in the heartland are being drained of their natural riches, with the result that crops increasingly depend on expensive chemical fertilizers.

In consequence, prices have climbed so high that the large middle class now requires two wage earners to support the same family that was easily supported by one wage earner in the '50s. If that is what is happening in the most technologically advanced country in the world, the implications for the less advanced are grim indeed.

John G. Clark, in his 1990 book, *The Political Economy of World Energy*, shows that in 1987 the United States consumed a total of 10 436 petajoules of energy [see figure]. (A petajoule—10^{15} joules—is the energy content of approximately 175 000 barrels of oil.) Although the detailed patterns of energy consumption vary from region to region around the world, two facts are undeniable: the bulk of the world's energy comes from irreplaceable fossil fuels, and growth in the less developed areas is proceeding at a greater relative pace than in the more industrialized regions.

> Today, most applied economics is aimed at supporting an unachievable model: unlimited growth

Clearly, as underdeveloped countries begin to expand their economies, the rate of consumption worldwide will accelerate. What is needed are substitutes for the rapidly disappearing fossil fuels, which currently supply a full 90 percent of our total energy needs.

The most suitable substitute would be nuclear power were it not for its high cost and unresolved waste management problems. Others, like solar, geothermal, wind, and hydroelectric power, cannot even meet the bulk of present needs, let alone those of the future.

Comments are invited

The editors of *IEEE Spectrum* recognize that some of the ideas in this article may be controversial, but feel that the subject is of critical importance. We are publishing it, therefore, in the hope of stimulating an exchange of ideas on the several topics discussed by the author. Readers are encouraged to send their comments to Michael J. Riezenman, Senior Editor, at *IEEE Spectrum*, 345 East 47th St., New York, NY 10017. Alternatively, responses may be transmitted to the *Spectrum* electronic bulletin board at 212-705-7308 (1200-N-8-1) or faxed to 212-705-7453.

Perhaps the brightest hope for the future is fusion electric power generation, with its relative absence of harmful radiation waste products. However, the technology is proving to be very difficult to exploit. Though great strides have been made, researchers have been unable to sustain a fusion reaction, let alone build a practical generator.

The IEEE's present position paper on fusion energy supports a government goal for a demonstration of practical power production by the year 2025, and the first commercially viable on-line plant by the year 2040. During those 50 years, energy efficiency to extend the use of natural resources is expected to become ever more critical, especially for home and for automobiles.

WATER CRISES. Water, too, can be added to the list of depletables, along with oil, gas, and coal, which have been exploited at low cost in the past to support economic growth. In her article last year in *World Magazine*, Diane Ward shows how much of the fresh water consumed by mankind throughout the world is provided by deep aquifers [see To probe further, p. 45]. One vital aquifer runs under parts of the Sahara desert. Another, the Ogallala, runs under eight thirsty states in the U.S. Southwest, and waters one-fifth of the irrigated cropland in the United States.

These aquifers have been charged over hundreds and even thousands of years by river and stream seepage and by rainfall. Not only are the aquifers being depleted by excessive pumping ("water ranching" has become a big business in the Southwest United States), but their sources, such as the Colorado River system, have been exploited to the point where their ability to replenish the aquifers has been seriously compromised.

Raymond S. Larsen ASA Instruments Inc.

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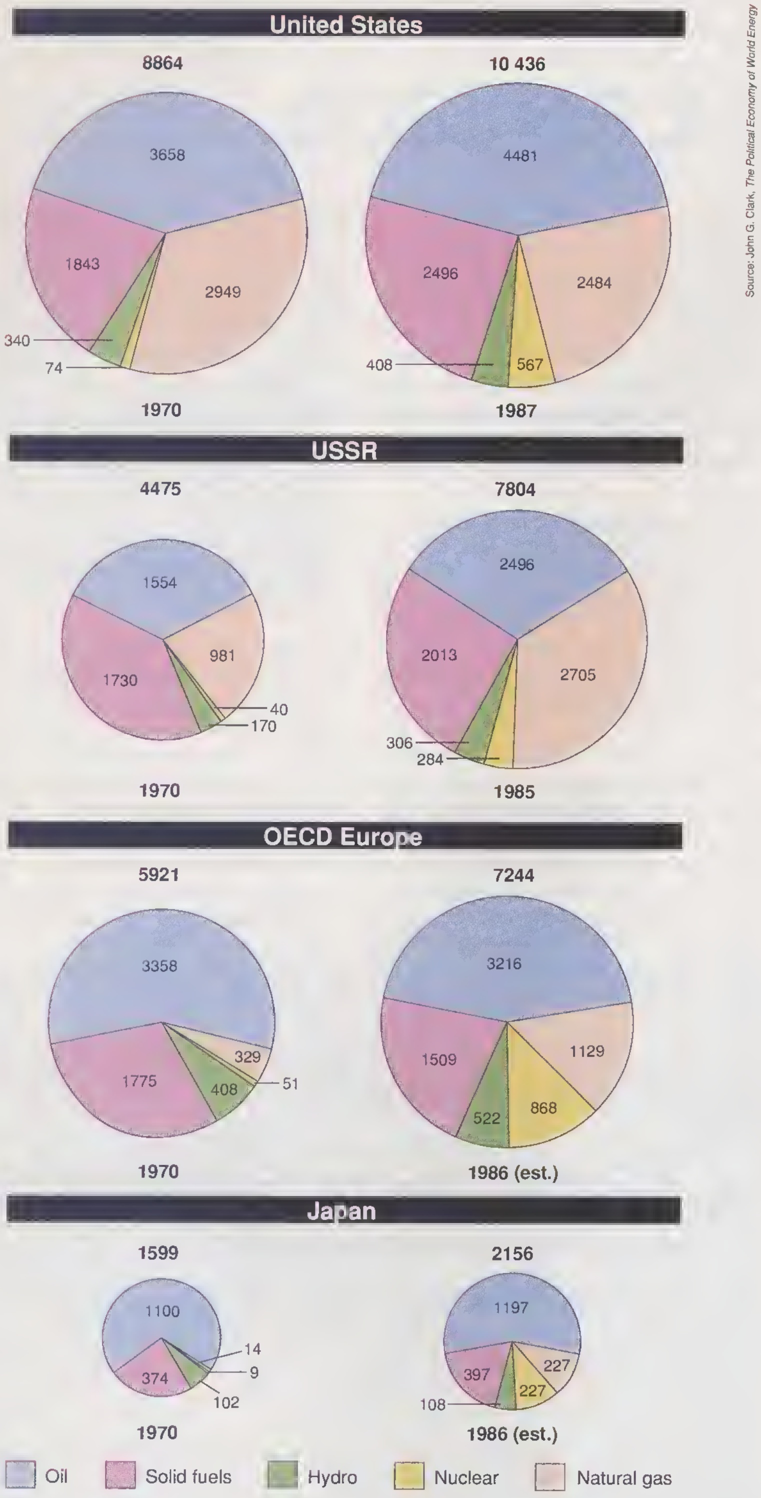
Patterns of energy consumption in four industrialized regions



Consumption of fossil fuels [shown in these pie charts in petajoules] is increasing. Although these fuels form a smaller fraction of the energy pies now than in the past, the pies are getting larger. Note that energy consumption is increasing fastest in the least developed areas. The Soviet Union's consumption grew by 74 percent over the studied period, while that of the United States went up by only 18 percent. The figures for Japan and the European member nations of the Organization for Economic Cooperation and Development increased by 35 and 22 percent, respectively. Those numbers suggest that global consumption will accelerate rapidly as the Third World becomes more industrialized. (A petajoule—10^{15} joules—is the energy contained in approximately 175 000 barrels of oil.)

A side effect of depletion is the inevitable collapse of the mined-out aquifers, destroying them top-down forever for future generations, as well as damaging the surface extensively.

Obviously, fresh water can be extracted from the oceans, but only at a high cost in capital equipment and energy. Large population centers in most countries of the world will face increasing or even critical shortages in the near future. In several areas, the cost of water is about to soar.

TECHNOLOGY TO THE RESCUE? Notwithstanding these shortages, technology proponents are predicting that science will come to the rescue. They are confident that substitutes will be found for the exhaustible natural resources: artificial fibers for cotton to make clothing, the paperless society to save the trees, and solar-powered vehicles and fusion-generated electricity to circumvent depletion of fossil fuels and the attendant pollution. To do any good, these advances have to begin now; yet they remain as concepts and research projects, some of which predictably will not succeed.

Unfortunately, technology, which drives the world economy, has no ethics of its own. Moreover, it is incapable of transcending the very laws that govern it, most obviously the second law of thermodynamics, which in effect states that everything comes at a cost.

Worse yet, thanks to technology, humanity is able to exploit the irreplaceable at an ever-faster pace, creating temporary wealth for a privileged few among the world's people. Instant worldwide communications, the facsimile machine, and that latest scourge of the superhighways—the car phone—are all aimed at getting an even faster jump on competitors, thus further accelerating the depletion of natural resources.

In the short run, the illusion of creating something out of nothing at no cost holds up just fine. All participants can prosper as long as the forests hold out, the fish still run, the oil still flows, the gold is still mined, the ground is still rich, the water does not run out, and the air remains clean.

But this approach just taps a long list of finite—not infinite—resources. All the resources to be tapped may not have been discovered yet. Some may even be manufactured artificially in the future, at the expense of, at a minimum, energy. But the underlying fact remains: *the world's critical resources, all of them, are being exhausted.*

Over the long term, the evidence suggests that the world economy is inevitably a negative-sum game—that is, real global wealth will decline, forcing growing economic disparity among nations, as well as among citizens within a nation. Until strong evidence to the contrary emerges—possibly, but improbably, in the form of major scientific breakthroughs—it will be prudent to calculate the sums very carefully. Within the IEEE, it behooves us as technologists to apply our best intellects to the technical issues and our best social instincts toward

planning our future. And as purveyors of technology, we should recognize our responsibilities toward global humanity.

Technology will have an even greater effect on our future than it has had on our past. Properly applied, it can help enormously toward developing ways to live in a negative-sum world. Misapplied, it can hasten a global crisis. But in either case, it cannot change the sign of the equation.

THE TECHNOLOGISTS' BURDEN. At the core of any economic debate lies technology—what it can do, and what it cannot; both its promises and its limits must be recognized. Technologists are needed in the core debate, but they must be armed with much more than just technical knowledge and personal opinion. And they must contribute as a group, rather than as hired guns to support one preconceived political view or another.

We technologists in the IEEE and elsewhere need to acquaint ourselves with both the economic discussion and the political tools used in attempts to manage economics on behalf of the nation. This will be a drastic change, but a necessary one, for a group that traditionally lets economists and politicians do its thinking in these areas.

Today, most applied economics is aimed at supporting an unachievable economic model: unlimited growth. Also, economists ultimately work for others whose agenda is to do the best they can for their constituents. This is interpreted to mean more material wealth for all the people within a nation. But it is impossible to have more for all, even within a nation, let alone among nations. Therefore, the need to face reality, and to insist that our planners do so, is paramount.

Another need is to focus on transnational economic models because without them the solutions reached will be nonsensical. Rich nations will be reluctant to do this, but unless they do, the model is doomed to failure. Also, more than ever, we need to question the moral and ethical implications of technical-economic decisions as they affect others worldwide. This is perhaps not much different in principle from examining those deciisions within a nation, but it is much more challenging.

If the world economy is really a zero-sum or negative-sum proposition, there is no longer an *us* and a *them*; there is only *us*.

IEEE'S ROLE. As a transnational organization, the IEEE has a tremendously diverse constituency, encompassing a wide range of social and economic structures. It should call upon its members to contribute toward debate, the development of a consensus, public and self-education, and future planning. To be effective, it needs to create both an internal structure and external relationships that reflect its transnational character.

The Institute must become informed in both economics and politics, so that it can become a useful part of the interdisciplinary team required to address these broad problems. No longer is it enough to explain technological tradeoffs to decision-makers and then retreat to the comfort of the laboratory. The decision-makers must be held accountable to the public interest. The IEEE must be not just an observer or a lobbyist, but a partner in leadership as well.

Within the framework of addressing global issues vital to the future of humankind, the engineering and scientific entrepreneurial communities need to be challenged. We must learn how to participate and how to use the tools of both technology and politics to do so; but we also need to rise above regional or national politics.

> The IEEE must be not just an observer or a lobbyist, but a partner in leadership as well

Building a consensus among ourselves is necessary, but at the same time we have to expand our horizons as part of a team dedicated to solving global problems. Not only must we explain the technology-cost tradeoffs of a traditional growth-economy model, but we should point out the technological, societal, and ecological cost tradeoffs of the zero-sum or negative-sum models, which more accurately represent the future.

These are issues that every IEEE member, and every aspiring IEEE member, should be called upon to consider. The Institute has a challenging role to play in making this happen. Along with our continuing emphasis on education and professionalism, these global issues should be our dominant theme for the future.

TO PROBE FURTHER. For an excellent review of the various factors contributing to the world's economic problems and proposed solutions, including the role of technology, three books by economist Lester Thurow of the Massachusetts Institute of Technology are recommended: *The Zero-Sum Society* (Viking Penguin, New York, 1981), *The Zero-Sum Solution* (Touchstone, New York, 1986), and *Head to Head: The Coming Economic Battle Among Japan, Europe, and America* (William Morrow & Co., New York, 1992).

John G. Clark gives a good overview of the development of the modern energy mix, and the political-economic reasons driving the choices that have been made, in *The Political Economy of World Energy: A Twentieth Century Perspective* (University of North Carolina Press, Chapel Hill, 1990).

Bernard L. Cohen's defense of nuclear power's relative safety, "Reducing the Hazards of Nuclear Power: Insanity in Action," is to be found in the July 1987 issue of *Physics and Society*, pp. 2–4.

The IEEE positions on various energy issues can be obtained from IEEE-United States Activities, Energy Policy Committee, Washington, DC; 202-785-0017.

Diane Ward's article "Water's Worth" appeared in *World Magazine*, Vol. 26, no. 2, pp. 20–35, published by KPMG Peat Marwick, New York, 1992.

A collection of discussions on sustainable societies can be found in *Preparing for a Sustainable Society*, Proceedings of the Interdisciplinary Conference, Ryerson Polytechnical Institute, Toronto, June 21–22, 1991. Conference co-sponsors included the IEEE Society on Social Implications of Technology and the IEEE Toronto Section.

For an overview of the planet's ecological crises, see Vice President Al Gore's highly readable book, *Earth in the Balance: Healing the Global Environment* (Houghton Mifflin Co., Boston, 1992). Some people regard Gore as an alarmist, but his warnings are mild compared with the apocalyptic outlook of Herbert Gruhl, whose book *Ein Planet Wird Geplündert* is available only in German (Fischer Taschenbuch, Frankfurt am Main, 1992; U.S. residents will probably prefer to obtain it from Albert J. Phiebig Books, White Plains, NY). A translation of the short essay "Mankind is at an End," which appeared in *Der Spiegel*, no. 113, 1992, is available from the author.

A classic paper, "World Population Growth and Related Technical Problems," by Arthur L. Austin and John W. Brewer, discusses the global ecological effects of the population explosion. It appeared in *IEEE Spectrum*, December 1970, pp. 43–54.

For a sociologist's view of the role of associations in a democratic society, see Robert N. Bellah et al., *Habits of the Heart: Individualism and Commitment in American Life* (Harper Collins Publishers Inc., New York, 1986). The title comes from an expression used by Alexis de Tocqueville in *Democracy in America*, his classic commentary on the developing U.S. society. ◆

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Larsen has served the IEEE in many capacities, including two terms on the Administrative Committee of the Nuclear and Plasma Sciences Society, of which he was president from 1989 to 1990. He is a member of the IEEE Society for Social Implications of Technology. His interest in transnational and global issues stems partly from his dual citizenship in the United States and Canada and partly from association with many scientists, engineers, and business people in Europe, Japan, and China.

Working with neural networks

Evaluating neural networks for applications requires a good prior grasp of the necessary algorithms and development techniques

Neural networks have emerged as a powerful pattern recognition technique. Since the need for pattern recognition arises whenever computers interact with the real world, neural networks are broadly useful in a range of applications. Their evaluation for use in a particular application must be based on a knowledge of their strengths and weaknesses, the types of applications they are likely to succeed in, and the practical tasks of development. These topics are the focus of this article, the second of two on neural networks [see "Neural networks at work," June, pp. 26–32].

Like other pattern recognition techniques, neural networks act on data by detecting some kind of underlying organization. For example, scanned characters can be classified as different letters of the alphabet by detecting how they resemble one another. The networks can recognize spatial, temporal, or other relationships and can perform such tasks as classification, prediction, and function estimation. They can bridge the gap between individual examples and general relationships.

The networks learn the similarities among patterns directly from instances of them. That is, they infer solutions from data without prior knowledge of the regularities in the data; they extract the regularities empirically. This ability is a distinct asset in many applications because it works without conventional programming. Knowing something about the problem can improve the neural network designed for it, but the most critical need is data.

Developing a neural network is unlike developing software, because the network is trained, not programmed. Training one does not in itself require defining variables, creating loops, testing for conditions, running a compiler, or debugging code. Instead, the procedure starts with selecting, analyzing, and manipulating data, often using techniques from statistics and signal processing. This first step is usually the most crucial part of a neural net's development. While the network can infer relationships that its developer did not discern, it can find them only if the examples support the inference.

Most neural networks have parameters that control how they learn as they cycle repeatedly through the training data. The values selected for these parameters influence how well the trained network performs. Largely due to the adaptive or empirical nature of the neural network algorithms, parameter choice requires experimentation, and the results depend in part on the developer's experimental technique.

Finding suitable parameter values by experiment has been an impediment to the development of these networks, especially because some of the algorithms consume large amounts of computer time. A single training run has often taken hours, days, or even weeks on workstations. The multiple training runs needed to fully explore a wide range of possible solutions have been out of the question, forcing developers to limit problems artificially. Parallel hardware designed especially for the networks removes or reduces this computational barrier, thereby accelerating the networks' development.

> A neural network can learn something different from what its trainer had in mind

Training the networks is an emerging discipline that involves aspects of programming, statistics, and signal processing. For some problems, it can be faster than writing traditional software. It can also solve some problems that have resisted solution by other methods. Nonetheless, neural networks can be difficult to train and unsuitable for some tasks.

So why use them? Because they offer valuable characteristics unavailable together elsewhere. First, as mentioned, they can infer subtle, unknown relationships from data. This characteristic is useful because gathering data does not require explaining it. Second, the networks can generalize, meaning they can respond correctly to patterns that are only broadly similar to the original training patterns. Generalization is useful because real-world data is noisy, distorted, and often incomplete.

Third, they are nonlinear, that is, they can solve some complex problems more accurately than linear techniques do. Nonlinear behavior is common, but can be difficult to handle mathematically. Finally, neural networks are highly parallel. They contain many identical, independent operations that can be executed simultaneously. This is useful because parallel hardware can run neural networks quickly, often making them faster than alternative methods.

INSIDE STORY. Before reviewing the practical side of engineering these networks, it may be helpful to look at how they work. A good example is a three-layered network that learns with the back propagation (BP) algorithm. This type of network is a reasonable choice as an illustration because it is versatile and popular. Not all networks have three layers, however, and back propagation is not the only learning method. But even though some other type might serve a given purpose better than the one described, the key concepts apply to most neural networks.

A network using BP can be understood on several levels. On one level, it is a collection of vector equations; on another, a computer program; and on yet another, a layered system of interacting nodes [Fig. 1].

Each node is a single processing element that acts on data to produce a result. Typically, the nodes are arranged in layers and are each connected to the nodes in the preceding layer for input and the following layer for output. Furthermore, each connection has an associated adjustable value called a weight.

Data enters the network through the input layer. The nodes in the input layer are passive, not computational; each simply broadcasts a single data value over weighted connections to the hidden nodes. Each BP node also has an extra input called the threshold input, which acts as a reference level or bias for the node. All hidden nodes

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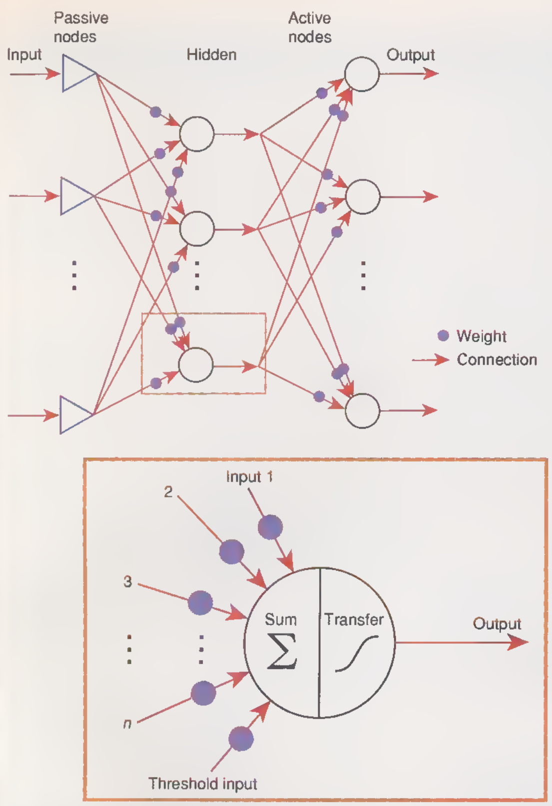


[1] Neural networks are made out of neuron-like nodes that are arranged in layers and pass data through weighted connections. The networks learn by changing the values of their weights. With suitable weights, such a network can model any computable function. A node in such a network typically multiplies each input by its weight, sums the products, then (for back propagation training) passes the sum through a nonlinear transfer function to produce a result. The fundamental computation for a neural network is therefore the vector-dot product, and its computational speed depends on executing the underlying multiply-and-accumulate operations efficiently.

thus receive all input data, but because each has a different set of weights, the sets of values differ.

Each hidden node processes its inputs and broadcasts its result to the output layer. The output nodes also have distinct sets of weights and process input values to produce a result. For BP, the network's result is a set of continuously variable values, one per output node.

Hidden nodes have no direct connection to input or output. Introducing this intermediate layer enhances the network's ability to model complex functions.

The hidden and output nodes process their inputs in two steps. Each multiplies every input by its weight, adds the product to a running total, and then passes the sum through a function to produce its result. This transfer function is usually a steadily increasing S-shaped curve, commonly called a sigmoid function. The attenuation at the upper and lower limbs of the "S" constrains the raw sums smoothly within fixed limits. The transfer function also introduces a nonlinearity that further enhances the network's ability to model complex functions.

The key to the back propagation learning algorithm is its ability to change the values of its weights in response to errors. For it to be possible to calculate the errors, the training data must contain a series of input patterns labeled with their target output patterns. (Labeled training data is a common, but not universal, requirement for neural networks.)

During BP training, a network passes each input pattern through the hidden layer to generate a result at each output node. It then subtracts the actual result from the target result to find the output-layer errors.

Next, the network passes the derivatives of the output errors back to the hidden layer, using the original weighted connections. This backward propagation of errors gives the algorithm its name. Each hidden node then calculates the weighted sum of the back-propagated errors to find its indirect contribution to the known output errors.

After each output and hidden node finds its error value, the node adjusts its weights to reduce its error. The equation that changes the weights is designed to minimize the sum of the network's squared errors. This minimization has an intuitive geometric meaning. To see it, all possible sets of weights must be plotted against the corresponding sum-of-squares (sum-squared) errors. The result is an error surface shaped like a bowl, whose bottom marks the set of weights with the smallest sum-of-squares error. Finding the bottom of the bowl—that is, the best set of weights—is the goal during training.

Back propagation achieves this goal by calculating the instantaneous slope of the error surface with respect to the current weights. It then incrementally changes the weights in the direction of the locally steepest path toward the bottom of the bowl. This process resembles rolling a ball down a hill and is called gradient descent [Fig. 2]. Gradient descent improves the network's overall accuracy as a result of the aggregate corrections during training. Back propagation is in effect a procedure for finding the weights that minimize sum-of-squares error.

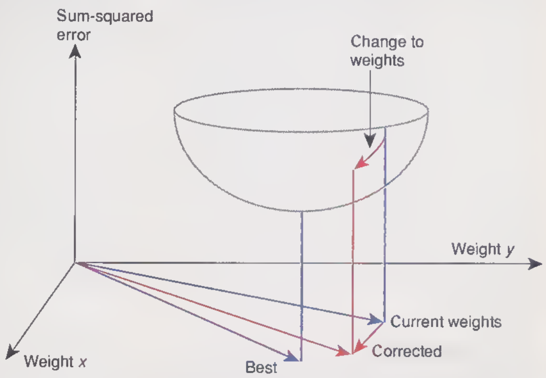
Real error surfaces can have complex ravine-like features and many dent-like local minima. Since gradient descent always follows the locally steepest path, the BP algorithm can train a network into a local minimum that it cannot escape. This effect depends on the exact path down the gradient, which in turn depends on the initial values of the weights and other factors. It is worth trying several configurations to see which has the least error.

In practice, finding the unique global minimum seldom matters. What does matter is finding a set of weights that processes data accurately enough for the application. Saving these trained weights preserves what the neural network learned and enables it to play its part in the application without further training.

This network architecture (three fully connected layers) and learning algorithm (BP) are representative merely. Not all the details apply to all networks. Structural elements such as nodes, connections, layers, and weights are practically universal, but the arrangements between them vary. For example, some networks lack a hidden layer, and some have two or more. Other variations include nodes that feed back to earlier nodes, connections that skip layers, and layers that are only partly connected.

The learning algorithms, or the mathematical rules controlling weight updates, also vary. While specific algorithms are often paired with specific architectures, network structure and behavior are independent. Consequently, a three-layer network like the one described might not use BP, and BP might appear in another network .

Not all learning algorithms require repeated passes through the training data. Nor do they all require labeled data. Those that do are called supervised algorithms and require either a precise correct answer or only the fact that the result is good or bad. Learning needing only a grade is called reinforcement learning. Unsupervised algo-



[2] The back propagation algorithm learns by changing its weights to follow the steepest path toward the bottom of a bowl-shaped error surface. Shown here is an idealized error surface for two-dimensional weights. Real error surfaces typically have ravine-like features and dent-like local minima.

rithms do not use target results at all and typically find statistical relationships among training patterns.

PROGRAMMING COMPARED. Neural networks imitate functions on the basis of their measured behavior. This fundamental ability, which is called function modeling, estimation, or approximation, appears in many guises, such as classification, prediction, clustering, and pattern recognition. A mapping task is an example of function modeling.

Traditional computer programs can do similar tasks, and the two computational models overlap in some cases. In practice, they have opposite strengths, and some tasks that are simple for one method are barely possible for the other.

Traditional computer programs tend to be good at tasks that require high numerical accuracy or the manipulation of symbols. An example is balancing a checkbook, because exact rules are easy to define and perfect accuracy is critical. A neural network is likely to find this task hard to learn.

The advantage is reversed for tasks that have few obvious rules, deal with imperfect data, or optimize many constraints simultaneously. For example, controlling an industrial process can be a good task for a neural network, since often rules are difficult to define, historical data is plentiful but noisy, and perfect numerical accuracy is unnecessary. Programming a standard computer for the same task might require years of work, especially if the process happens to be nonlinear.

The neural network is rarely a standalone product, but usually part of a larger application, within which it acts much like a callable function: the application passes a set of values to the neural network, which passes back a result.

APPROPRIATENESS. The first step in matching an application and a neural network is to weigh the characteristics, requirements, and drawbacks of each. Factors such as computational speed also matter.

As implied above, one common characteristic of successful neural network applications is a function estimation task. Others include the need to cope with large amounts of imprecise data, the ability to tolerate an approximate result, or the presence of complex, nonlinear behavior.

A major requirement is the collection of training data. It must be possible to gather a sufficient sample of representative data; otherwise, it may be difficult or impossible to train a neural network. Often a related consideration is the need to label the training set with target results.

Neural networks have several drawbacks for some applications. First, they may fail to find a satisfactory solution, perhaps because there is no learnable function or because the data is insufficient.

Second, it can be hard to account for a neural network's results. For one thing, the results depend on thousands of calculations involving the input pattern and the connection weights. Showing how the weights "cause" a result may be more complex than showing how a computer program works. For another, the values of the weights are themselves the result of a complex machine-learning procedure, making their origin hard to explain.

Still, for most applications, this concern is only theoretical, since neural networks are often more accurate than other solutions. They are like statistics in their aggregate behavior, their usefulness, and their effectiveness in applications that lack other solutions and tolerate imprecision. They may be unsuitable when safety is critical or risks are to be avoided, unless they can be validated with all possible input values.

Third, neural networks can be slow and expensive to train. Part of the cost stems from the need to collect, analyze, and manipulate training data. Part comes from the need to experiment with parameters to find good values. Greater understanding of training protocols should help, especially in combination with parallel hardware that can run systematic experiments quickly.

A final aspect of neural networks worth examining is their computational speed in the finished application. Each connection requires a product to be calculated and added to a running total. Execution times consequently depend on the number of connections, typically roughly the square of the number of nodes. Small increases in the number of nodes therefore cause large increases in execution time. The data rates and response times the application needs must be supplied by the system running the neural network.

For example, by the above rule of thumb, 100 nodes entail about 10 000 connections. A standard microprocessor can calculate about 10 million multiply-accumulate operations per second, so it can pass through the network about 1000 times per second. If the application requires data rates and reaction times of a millisecond or less, then the microprocessor will suffice.

If, however, the application needs 300 nodes, then the network has about 900 000 connections, and the microprocessor can pass it through only about 100 times a second. The number of nodes has tripled, but the response time has risen tenfold. A microprocessor or digital signal processor may be unable to support the needed data rates or response times, and if so, special-purpose hardware should be considered.

This new hardware exploits the parallelism of neural networks and similar algorithms so as to increase their speed, often by several orders of magnitude. As a result, it can run full-scale networks at real-time rates, so that applications that need large networks can have them. Parallel hardware also enables applications that continue to

Defining terms

Back propagation (BP): (in a neural network) a supervised learning method in which an output error signal is fed back through the network, altering connection weights so as to minimize that error.

Connection: a link between nodes used to pass data from one node to the other. Each connection has an adjustable value called a weight.

Generalization: a neural network's ability to respond correctly to data not used to train it.

Global minimum: the unique point of least error during gradient descent, metaphorically the true "bottom" of the error surface.

Gradient descent: a learning process that changes a neural network's weights to follow the steepest path toward the point of minimum error.

Input layer: a layer of nodes that forms a passive conduit for data entering a neural network.

Hidden layer: a layer of nodes not directly connected to a neural network's input or output.

Labeled data: input patterns tagged with a target result, which provides the "correct" answer needed by supervised algorithms for training.

Layer: a set of nodes connected to common inputs, outputs, or both.

Local minimum: a point of regionally low error during gradient descent, a metaphorical dent in the error surface.

Mean squared error: a measure of accuracy, used by several neural networks, that is calculated squaring each error, summing the squares, then averaging the sum by the number of outputs and data patterns. Gradient descent minimizes mean squared error.

Memorization: (or overtraining) a neural network's tendency to learn random details in the training data in addition to the underlying function. A network that simply memorizes may fail to generalize.

Neural network: an implementation of a learning algorithm derived from research about the brain. Often referred to as artificial neural network, it typically contains layers of so-called artificial neurons composed of weights, connections, and nodes.

Node: a single neuron-like element in a neural network. It typically has many inputs but only one output.

Output layer: the layer of nodes that produce the neural network's result.

Pattern recognition: identification of shapes, forms, or configurations by automatic means.

Sum-of-squares error: a measure of accuracy, used in BP and some other network training procedures, calculated by squaring each error, then summing the squares.

Supervised learning: a learning process requiring a labeled training set.

Target result: a "correct" result included with each input pattern in a training or testing data set.

Testing: a process for measuring a neural network's performance, during which the network passes through an independent data set to calculate a performance index. It does not change its weights.

Training: (of a neural network) a process during which a neural network passes through a data set repeatedly, changing the values of its weights to improve its performance.

Unsupervised learning: a learning process that does not require a target result.

Weight : an adjustable value associated with a connection between nodes in a neural network.

Representative neural network (NN) development tools

Company	Overview	Software	Algorithm(s)	Hardware	Price
Adaptive Solutions Inc. Beaverton, OR	CNAPS is a SIMD parallel computer for pattern recognition, image processing, and NN development and deployment	CNAPS-C compiler; BuildNet; CodeNet; C Libraries (Unix)	BP, LVO2 (precoded for BuildNet and CodeNet)	CNAPS Parallel Computer; 6U VME board (NN-chip–based computer/VME card)	Hardware, US $15k–$95k; development software, $4.5k–$9k
AI Ware Cleveland, OH	N-Net is a user interface and C-program library for Functional Link Net, a patented algorithm for manufacturing and business applications	N-Net EX; N-Net 500 (DOS, Sparc, VMS)	Functional Link Net (supervised or unsupervised)	—	Software, $2k–$3k
California Scientific Software Nevada City, CA	BrainMaker is a menu-driven BP simulator that can import spreadsheet files; the Pro version has code for using trained NNs in applications	BrainMaker; Network Toolkit; BrainMaker Professional (DOS, MAC)	BP	BrainMaker Accelerator; Professional Accelerator (DSP-based AT cards)	Software, $195–$795; hardware, $2k–$13k
HNC Inc. San Diego, CA	ExploreNet is a Windows-based tool supporting popular algorithms and offering a path to hardware acceleration with the Balboa 860	ExploreNet; KnowledgeNet; DataBase Mining Workstation (Windows, Sparc, RS6000)	BP, Counter-propagation, LVO2, SOM, ART, PNN, others	Balboa 860 (DSP-based AT/VME card); HNC SNAP (NN-chip–based card)	Software, $395–$16k; hardware, $7.2k–$60k
IBM Corp. Rochester, MN	Neural Network Utility is an interactive environment for development, a runtime one for deployment, and an API for applications	Neural Network Utility/2; Neural Network Utility/400 (OS/2, Windows, OS 400)	BP, ART1, SOM, constraint satisfaction (extendable with API)	—	Software, $500–$14k
Intel Neural Network Group Santa Clara, CA	Electrically Trainable Analog Neural Network (Etann) accelerates multilayer feedforward NNs; each chip has 64 analog processors and nonvolatile weights	iNNTS: iBrainMaker; iDynaMind; training software interface library (DOS)	BP, Recurrent BP, Madaline III	80170NX Etann chips; iNNTS development tools (with 2 chips); Etann multichip board	Chips, $940; development tools, $11.8k–$22k
Nestor Inc. Providence, RI	RCE, a proprietary classification algorithm, works with Ni1000, a neural network chip developed with Intel	Nestor Development System (NDS); development tools for Ni1000 chip	Restricted Coulomb Energy (RCE)	Ni1000 (in conjunction with Intel)	NDS, $2995; Ni1000, contact vendor
Neural Systems Vancouver, BC, Canada	Genesis is an NN development/deployment tool featuring a variant of BP with no need for explicit target results	Genesis (DOS)	BP	—	Software, $995
NeuralWare Pittsburgh, PA	NeuralWorks is a comprehensive NN development environment offering many algorithms and running on many platforms	NeuralWorks Professional II/Plus (DOS, Mac, Unix, VMS)	ART, BP, LVQ2, PNN, RBF, SOM, Cascade Correlation, others	—	Software, $1895–$8k
Neurix Cambridge, MA	MacBrain is an interactive NN simulator with customization hooks and a toolkit for SuperCard or HyperCard	MacBrain (Mac)	BP, Hopfield, Hebbian	—	Software, $1495
NeuroDynamX Boulder, CO	DynaMind creates, trains, and implements NNs, and has a user-friendly interface; DynaMind Developer adds a C library for applications	DynaMind 4.0; DynaMind Developer (DOS)	BP, Recurrent BP, Madaline III	Neural-Accelerators (DSP-based AT cards) (DynaMind also with Intel Etann)	Software $295–$1295; hardware, $3.5k–$9k
Ward Systems Group Frederick, MD	NeuroShell is a development tool that works with spreadsheet files; Neuro Windows is a dynamic link library	NeuroShell (DOS); NeuroShell 2; NeuroWindows (Windows)	BP, SOM, general regression NNs, PNN	NeuroBoard (RISC-based PC card)	Software, $195–$495; hardware, $1595

API = Application Program Interface; ART = adaptive resonance theory; BP = back propagation; DSP = digital signal processing; LVO2 = learning vector quantization; NN = neural network; PNN = probabilistic neural network; RISC = reduced-instruction-set computing; SIMD = single-instruction, multiple-data; SOM = self-organizing map.

learn after deployment.

DEVELOPMENT. Designing and training neural networks is a new branch of pattern recognition, in which aspects of statistics, programming, and signal processing combine with techniques unique to the networks. This interdisciplinary blend is a hallmark of an emerging specialty.

Part of evaluating the suitability of neural networks for an application is knowing the tasks needed to make them work, including design and training, selection of a general design procedure as well as the practical development tasks, and the evaluation of design choices and tradeoffs.

In general, it is best to try to build what is known about the problem into the data and into the network. For instance, suppose the neural network must discriminate among C, G, O, and Q. Here, the right side of the character is the most distinctive, so that the neural network could be trained with data from only the right sides. While it could learn to ignore the left sides on its own, forcing it to learn something already known only complicates its task. Alternatively, several neural networks could be trained to

detect distinguishing parts of letters used for final classification. Either way, building knowledge into the design almost always makes the neural network simpler and more accurate.

CREATING A DATA SET. The first and usually longest step in development, and also generally the most critical to eventual success, is the creation of a data set. Tasks here include gathering raw data, analyzing it, selecting variables, and preprocessing the data so that the network can learn efficiently. Some practitioners claim that collecting proper data is nine-tenths of the job.

Data is, in any case, paramount for a neural network: it is an empirical system. It can recognize new examples of the patterns used to train it, but only if they resemble the training patterns. For example, one trained to recognize A and B can spot new As and Bs, but not Cs and Ds.

The broad goal is to build a file of a series of input patterns, each of which is a set of measured values. Those networks that learn from a known result also require a target result for each input pattern. The entire pattern is usually seen as a vector, and the individual values as vector components. Building the input patterns generally requires choosing among many measurable variables. An industrial process, for instance, might permit monitoring pressures, temperatures, and flows at hundreds of points.

Which inputs are best? Here familiarity with the application is invaluable. Training a neural network to rate credit risks, for instance, implies having (or acquiring) expertise in credit rating; machine learning does not replace human skill. Also key to judging relevance is inspecting the raw data, typically by means of statistical techniques. Calculating the strength of the correlation between an input and an output, for example, suggests whether to include or exclude the variable. Similarly, a strong cor-

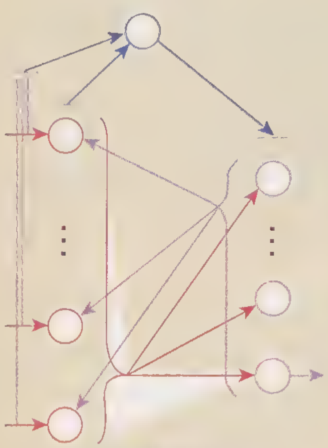
Popular neural network algorithms

The neural network described in the main text is currently the favorite. Many other networks have been developed, however, and might serve a given purpose better. The following descriptions of five representative networks offer a sense of how they work.

• Adaptive resonance theory (ART). In its most basic form, an ART network has two interacting layers. A pattern enters the network through the input layer [red circles], which encodes it and passes it to the output layer [purple circles] over weighted connections. The output layer then finds the output node closest to the pattern, suppresses the remaining nodes, and passes this "result" back to the input layer over a second set of weighted connections.

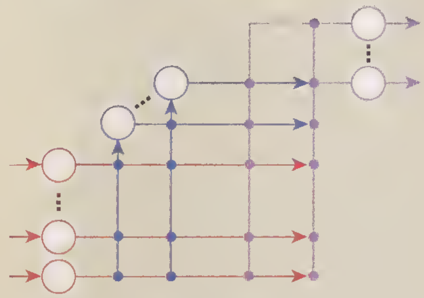
The input layer then finds its own result. If both results agree, then ART has identified the correct category, and the layers are said to be in adaptive resonance. If they do not agree, then ART tries the next-best match, and so on with the remaining output nodes. These alternatives might seem like worse candidates. Actually, ART trains continuously, so the weights differ slightly at each presentation. Eventually the layers resonate. Other mechanisms regulate learning [blue]; the overall effect is that ART finds categories autonomously and learns new categories if needed.

ART's continuous learning is one of its key benefits. Many other neural networks assume that the probability distributions in the data do not change over time. ART can follow nonstationary distributions, however, an asset for dynamic processes, and it does not require labeled training data. ART was developed by Stephen Grossberg at the Center for Adaptive Systems, Boston University, Massachusetts.



Adaptive resonance theory

• Cascade correlation (CC). CC is like BP, except that it can automatically add hidden nodes [blue,



Cascade correlation

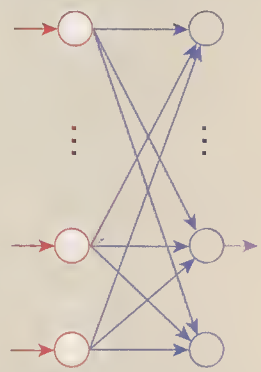
above] during training. Training starts with only input and output nodes [red and purple, respectively, above]. If this minimal network cannot become accurate enough, then CC creates a set of nodes connected to the inputs but not to the outputs. These nodes are candidates for addition to the network as hidden nodes. CC then trains them using a type of gradient descent to maximize the correlation between each candidate and the residual output error.

When the correlation stops improving, CC selects the best candidate node, freezes its weights [blue dots], and connects it to the output layer. This new hidden node becomes a permanent part of the network, and the output weights [purple dots] are retrained with the new node in place. This constructive process continues until the network reaches sufficient accuracy. Each new hidden node receives the network inputs plus the output from all previous hidden nodes, thereby forming a cascade of hidden nodes rather than a single hidden layer. CC thus determines its own size and topology, automatically generating a network of near-minimal size. CC eliminates guessing about the optimum number of hidden nodes and trains faster than BP. It was developed by Scott Fahlman, senior research computer scientist at Carnegie Mellon University, Pittsburgh.

• Learning vector quantization (LVQ2). This classifier adjusts the boundaries between categories to keep misclassifications to a minimum. An LVQ2 network has a single layer of computational nodes [red circles, below], each representing one class or subclass. For each input pattern [red arrows], LVQ2 finds the best-match output node [purple arrow], thereby classifying the pattern.

LVQ2 does not train through gradient descent. Instead, it finds the output node closest to the training pattern. If the training pattern's class differs from the output node's class, then LVQ2 finds the next-best match. If the next-best match has the correct class, then LVQ2 moves the best-match (but incorrect) node "farther" from the training pattern and the next-best (but correct) node "closer" to it. This process, called competitive learning, in effect moves the boundary between classes until it approximates the optimum position.

LVQ2 is commonly used for optical character recognition, converting speech or text into phonemes, and similar tasks. Unlike BP, it does not directly capture nonlinear features; it is also com-



Learning vector quantization

putationally simpler. LVQ2 was developed by Teuvo Kohonen, a professor at the Laboratory of Computer and Information Science at Helsinki University, in Finland.

• Probabilistic neural network (PNN). This classifier instantly approximates the optimum boundaries between categories, assuming that the training data is a representative sample. A network of this type has two hidden layers. The first [blue circles, next column] contains a dedicated node for each training pattern; the second [orange circles]

relation between two inputs might suggest that only one is needed.

After picking out the most significant inputs, most neural network developers examine their distributions. An input with a highly skewed distribution, for example, might require compensation for the skew, perhaps by scaling or other preprocessing. Most practitioners also inspect each variable for outliers, which are anomalous values outside the typical distribution. Some outliers are errors that can be corrected. Others are extreme but genuine values, which could be clipped so they do not have an undue influence.

Mathematical or statistical software packages offer a wide range of other techniques for evaluating data. Data analysis helps weed out the potential input variables so that only the most telling ones are used to build the training patterns. Data analysis also helps identify cycles, trends, and other relationships that can be extracted by preprocessing.

Preprocessing means transforming the data so that it becomes easier for the network to learn from. In fact, the form of the training data influences the results almost as much as the content. While on occasion data may be used raw, more often, it is transformed to yield salient features and to highlight high-order trends. In a process control application, for example, the absolute temperature might matter less than the rate of change, and transforming thermometer values into differences or differentials gives the neural network a head start.

Preprocessing may involve any mathematical operation. Common techniques include calculating sums, differences, differentials, inverses, powers, roots, logarithms, averages, moving averages, and Fourier transforms. Any signal-processing or feature extraction technique can be used. Similarly, one neural network may prepare data for another by, for instance, clustering the data before classification.

How much data is enough is a complex issue, and often affected by practical concerns such as the cost of gathering data. In general, the training set must provide a representative sample of the data the network will process in the finished application. Large training sets reduce the risk of undersampling the underlying function. (As in fitting a curve to a set of points, the more numerous the points, the better the estimate.) Too small, noisy, or skewed a training set, and the network can learn it perfectly but fail in the final application.

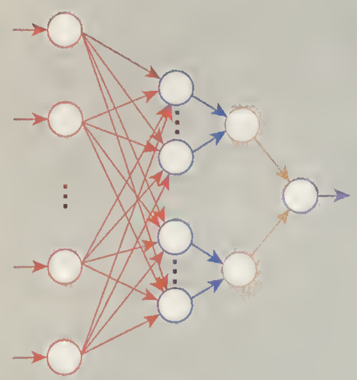
In practice, a sufficiency of data depends on several factors: network size, testing needs, and input and target distribution. The size of the network matters most. A big one usually needs more training data than a small one. A rule of thumb is to have five to 10 training patterns for each weight. One reason for care in selecting input and output variables is to keep the network small, so that less data is needed to train it.

Testing requires an independent data set. A simple way to prepare one is to divide the available data into two parts, holding back (say) one-third for testing. Selecting the testing patterns at random minimizes undesirable correlations between the training and testing data. Holding back a test set, however, leaves less data available for training (although techniques such as cross-validation do permit training and testing with the same data).

Another factor is the distribution of the input patterns and target results. Clustered distributions tend to decrease the amount of data needed. Distributions with subtle, overlapping features tend to increase it.

CONFIGURATION. Designing a neural network can be as simple as selecting a commercially available network, implemented in software, hardware, or combination thereoff, and configuring it to agree with the data. It can be as complex as coding a fully custom network from scratch—an approach beyond the scope of this article.

Neural network design choices include defining the behavior of the nodes, the training procedure, the topology of the network, and the values of the training parameters. Using commercial software typically sidesteps the low-level choices, since the



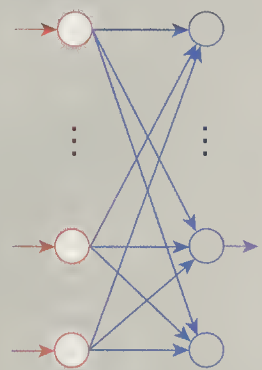
Probabilistic neural network

contains a dedicated node for each class. The two hidden layers are connected on a class-by-class basis—that is, the multiple examples of the class in the first are connected only to the single matching node in the second. Each "pattern" node [blue] calculates the weighted sum of its inputs plus bias terms, then passes the sum through a usually exponential function. Each "summation" node [purple] then sums the output strengths from the connected pattern nodes, or from all the examples of its class.

The pattern nodes pass their results to the output node, which compares them to find the "winning" class. In essence, PNN uses the training patterns to estimate the class probability distributions—each new input is classified according to the weighted average of the closest training examples. This network generalizes by means of a nonlinear "smoothing" function controlling behavior in the regions between the pattern nodes. Choosing the right value for the smoothing parameter influences the network's accuracy. PNN "trains" by simply storing the training patterns, not by using an iterative process. It therefore learns very rapidly, but large data sets require large networks. Clustering techniques can reduce network size. PNN was developed by Don Specht, consulting scientist at the Lockheed Palto Alto Research Laboratory.

• Self-organizing map (SOM). This clustering algorithm creates a map of relationships among input patterns. The map is a reduced representation of the original data that preserves its topological relationships—that is, the map has fewer dimensions but the clusters keep their relative positions. SOM creates the map from a random starting point without target results. A SOM network resembles an LVQ2 network. Both have a single computational layer [blue circles, below] and use a distance metric to find the output node [purple] closest to a given input pattern [purple]. But unlike LVQ2, SOM output nodes do not correspond to known classes, but to unknown clusters that SOM finds in the data autonomously.

During training, SOM finds the output node that has the least distance from the training pattern. It then changes the node's weights to increase its similarity to the training pattern. It also changes the



Self-organizing map

weights of a block of adjacent nodes even though they have only random relationships to the training pattern. Each winner thus influences its neighbors, and different training patterns trigger different winners with different neighbors. The overall effect is to move the output nodes to "positions" that map the distribution of the training patterns. After training, each node's weights model the features that characterize a cluster in the data.

SOM finds natural clusters or feature similarities from unlabeled training data. Examples of SOM applications include data compression, feature extraction, and preprocessing weights or data for other networks.

A data compression application, for example, could use SOM to find clusters in a sample of uncompressed data. During training, the network changes its weights so that each output node stands for a cluster. After training, the network encodes data by matching each uncompressed pattern to the closest output node. SOM was developed by Teuvo Kohonen, of Helsinki University, who also developed LVQ2. —*D.H.*

general network structure and behavior are built in as standard, selectable algorithms [see table]. What remains is choosing an algorithm, configuring a network to agree with the data, and training it while selecting values that influence training.

Assuming standard software, the first choice is which network to use. This decision is closely tied to the data and application, making it difficult to offer general advice. Probably the best place to start is to study the best-known networks [see "Popular neural network algorithms," p. 50]. If possible, also study previous neural network applications that are like the task at hand. Proceedings of technical conferences sponsored by the IEEE and others include many papers on successful applications.

While there are no hard-and-fast rules for matching algorithms to applications, a few broad guidelines may be based on the strengths, weaknesses, and requirements of individual algorithms. BP algorithms, for instance, tend to do well at function estimation and time series tasks, especially if the desired result is easily expressed as a set of continuously variable values. BP is also good at representing complex, nonlinear relationships in the form of a compact, efficient network. Finally, BP is relatively easy to use.

On the other hand, BP tends to learn slowly, which has limited it to problems that tolerate off-line learning or that have relatively stable underlying relationships. Finally, it is not guaranteed always to find the best solution.

Learning vector quantization (LVQ2), to take another example, can be an excellent classifier, especially if the desired result is easily expressed as a token representing a category. This characteristic makes LVQ2 a natural for, say, optical character recognition. On the other hand, LVQ2 is less suited to more general function estimation tasks or time series prediction tasks. Also, its computational simplicity is sometimes offset by the need to use more nodes to get the same results as an equivalent multilayer network.

Sometimes the available data dictates the choice of network. For example, BP, LVQ2, and many other algorithms are supervised and must have training data labeled with target results. If target results are unknown, then supervised algorithms are useless. This leaves unsupervised algorithms such as self-organizing map (SOM), mainly useful for clustering and data compression applications. Unsupervised algorithms are also often used in conjunction with other algorithms, for example, to preprocess data for them.

An example might be a situation where plenty of training data exists, but only a fraction has been labeled. Here, a SOM network could place the unlabeled data in clusters centered on the labeled examples, thereby labeling the remaining data.

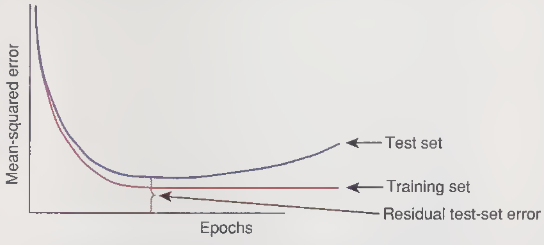
Often, several networks seem equally suitable. Many perform classification, for instance, and typically there is no way to decide beforehand which is best for the problem. One suggestion is to forget about finding a theoretical rationale, especially since the training data contains unknown relationships, and instead to try several plausible candidates, then focus on the best one.

After choosing a network, the next step is configuring it by setting the number of input and output nodes to agree with the number of inputs and outputs in the data. Some networks require extra values to be assigned. A BP training, for example, requires a preliminary value for the number of hidden nodes—the final value depends on experiments during training.

Some neural network software permits control over other aspects of network configuration. For a BP training, for example, the software implementing the algorithm might allow changing the number of hidden layers, the type of transfer function, the frequency of weight updates, and other factors. Additional structural variations include limiting the number of weights by omitting some connections or by sharing weights among connections. These refinements sometimes add extra speed or accuracy in a finished application.

TRAINING AND TESTING. The final development step is training and testing the network. During training, most of them cycle through the data repeatedly, changing the values of their weights to improve performance. Each pass through the training data is called an epoch, and the neural network learns through the overall change in weights accumulating over many epochs. Training continues until the values of the weights cause the network to map input patterns to appropriate results.

The glamorous fact that neural networks learn the training data sometimes obscures the awkward detail that not everything they learn is useful. A network can learn something different from what its trainer had in mind. It can also memorize the training examples without learning what they have in common. In an extreme case, a neural network acting as a look-up table may recognize every training pattern but not even one novel pattern. Results measured with the training data therefore say very little about the neural network's reliability in the application. A neural network is useful only if it returns appropriate results with data not used to train it. Measuring this ability, called generalization, requires testing the network with an independent data set.



[3] Network training aims for a configuration that can generalize to nontraining data. For a back propagation training procedure, generalization may be evaluated by examining mean squared error measured with an independent data set. Test-set error typically falls at first, then rises when the network begins to memorize the random details in the training data. Ending training at the minimum point yields the best performance with nontraining data. The configuration with the lowest residual test-set error is the best for the problem.

During testing, the network passes the testing patterns forward through itself and calculates a performance index such as mean squared error without changing the weights. The real goal during training is test-set, not training-set, accuracy. A good way to achieve this goal is to interleave training and testing, trying different network configurations while monitoring a performance index. Testing during training shows when to end training to prevent inappropriate memorization, also called "overtraining." It also shows which configuration is best.

Trying different configurations is a matter of changing parameters that control network structure and behavior. For backward propagation, these parameters set such things as the size of the update applied to the weights, the number of input patterns between each pair of updates, and the number of hidden nodes. The parameter values assigned can have a large impact on the performance of the system. As there is seldom any way of deducing the best values, training requires experimentation.

Training is therefore an interactive process: the trainer tries a configuration, evaluates a result, makes a change, tries it again, and so on until satisfied. This trial-and-error approach has hampered neural network development, because it has often been impractical to try enough combinations of parameters. Parallel hardware, though, makes systematic methods more feasible. Given sufficient computational speed, the developer can write a program that increments several parameters in nested loops, exploring all permutations to find the best generalization.

The parameters controlling network size have a large impact on generalization. In a network using BP training, the number of hidden nodes has a particularly large impact. These networks with too many hidden nodes tend to memorize the training data; those with too few cannot learn to answer the problem. Choosing an appropriate number is a good illustration of training through experimentation. It also exposes the statistical issues affecting generalization.

A large network has many weights with which to represent the details of a function. For complex functions, this is an advantage, if the training data is sufficient for an accurate model. Other-

wise, excessive weights can be a drawback, since the neural network can use them to memorize the training data. A smaller network has fewer weights, forcing it to learn the underlying function and permitting it to generalize beyond the training data. Too small a network cannot learn the problem at all, however.

A critical goal during training is to find a network that is large enough to learn the application but small enough to generalize well. The best performer is the network with the fewest weights needed to process the testing data accurately. In practice, this "ideal" size is related to the quantity and quality of the training data.

Many methods have been described for eliminating weights, including pruning out those that do not contribute to accuracy, omitting them between some nodes, and sharing them among some connections. The simplest is limiting the number of nodes, since each node has many weights. The number of input and output nodes depends on the data and is fixed during training. As a result, choosing the number of weights is the same as choosing the number of hidden nodes.

A reasonable strategy is to start with a few hidden nodes and increase the number while monitoring generalization by testing at each epoch. The most common index of generalization for BP is mean squared error, calculated by squaring each error, summing the squares, then averaging the sum by number of outputs and data patterns. A good technique for preventing overtraining is to stop when the mean squared error yielded by the testing set stops improving.

Test-set and training-set mean squared error both typically fall rapidly at the beginning of training as the network moves its weights away from their original random positions. In time, both curves become flatter. Typically, training-set error continues to decline, but test-set error eventually begins to increase [Fig. 3]. This increase shows that the network has stopped learning what the training patterns have in common with the test patterns and started to learn meaningless differences. This overfitting of the training data harms the network's ability to generalize, since it is merely memorizing the noise in the training data.

As a result, the mean squared error measured with the training set can be a deceptive index of performance. In fact, a network with a falling training-set error may be getting worse on test-set performance. Again, for best generalization, training should stop when test-set mean squared error reaches its lowest point (usually identified after the fact). Further learning offers no benefit, and the fact that one configuration ultimately reaches a lower training-set mean squared error than another is no basis of choice between them.

The real basis of choice is the error remaining at the best test-set performance. This residual error varies with configuration. The network with the least residual error is assumed to be the best one for the problem.

The number of hidden nodes influences the residual error. Ideally, there is some optimum number of hidden nodes producing the smallest residual error, with larger and smaller numbers of hidden nodes both producing larger errors. Real networks trained with real data do not always exhibit this behavior cleanly. Nevertheless, monitoring error measured with a separate test set while varying the number of hidden nodes is a key strategy for optimizing performance with a BP training.

> A critical goal during training is to find a network large enough to learn the task but small enough to generalize

Many of the details described above are specific to BP. For example, the value used to measure performance varies from algorithm to algorithm, which also vary in their susceptibility to overtraining. Nevertheless, the basic approach—experimenting with parameters while monitoring a performance index—applies to neural network training generally. The technique of interleaving the processes of testing and training is also widely applicable.

WHAT NEXT? For many, the jumping-off point is a commercial software package. These packages start at a few hundred dollars and run under DOS, Mac, or Unix. Commercial software often makes initial exploration easier because it bypasses programming the neural network algorithms. If the final application can run fast enough on a PC or workstation, then the commercial packages may be sufficient.

The table lists some representative development systems currently available for neural networks. It includes both software and hardware systems, focusing on general-purpose tools and omitting systems aimed at niches such as financial forecasting and optical character recognition. Programmers who want more insight into the algorithms should consider coding them from scratch. For BP, try D. Rumelhart and J. McClelland's *Parallel Distributed Processing* series, which includes the classic description of BP as well as a disk with sample code.

Many long-time neural network researchers have written entire suites of development tools for themselves. Their efforts reflect the newness of the discipline as well as their need for flexibility during research. The increasing maturity of commercial packages makes getting started much easier, especially if the goal is practical application rather than pure research.

Depending on network size and application requirements, the trained neural network might or might not run fast enough on a workstation or desktop PC. Accelerator cards based on digital signal processors improve speed. Parallel hardware dedicated to neural network and similar applications is even faster, permitting large networks for real-time applications.

TO PROBE FURTHER. Applications of neural networks to such tasks as optical character recognition, financial forecasting, and process control are discussed in "Neural networks at work," by this author, *IEEE Spectrum*, June 1993, pp. 26–32. A paper citing more than 150 references is listed in that article's To probe further.

Among relevent societies and-conferences is the IEEE's Council on Neural Networks, which is sponsoring the International Joint Conference on Neural Networks to be held Oct. 25–29 in Nagoya, Japan. Contact: Toshio Fukuda, Nagoya University, Department of Mechanical Engineering, Furo-Cho, Chikusa-Ku, Nagoya, Japan; (81+52) 781 5111, ext. 4478/3301; fax, (81+52) 781 9243. Also, the IEEE's Information Theory Society sponsors the Neural Information Processing Systems (NIPS) meeting, held toward year-end in Denver, CO.

The European Neural Network Society (ENNS) sponsors the International Conference on Artificial Neural Networks (ICANN).

The International Neural Network Society (INNS) sponsors the World Congress on Neural Networks (WCNN), which this year is being held July 11–15 in Portland, OR. Contact: INNS, Suite 300, 1250 24th St., N.W., Washington DC 20037; 202-466-4667.

Papers discussing neural networks appear regularly in the *IEEE Transactions on System, Man and Cybernetics* and in the *IEEE Transactions on Neural Networks*. Other periodicals include the *International Journal of Neural Systems* from World Scientific Publishing; *Neural Computation* from MIT Press; *Neural Networks* by Pergamon Press; and the journal of the INNS. ◆

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The Calstart consortium

Many eyes are on an enterprising attempt to solve the 'peace problem' by creating an electric vehicle industry in California

One of the most ambitious—and problematic—defense conversion endeavors to date can be found in an abandoned aircraft plant near the Burbank, CA, airport. There, in a 14 500-square-meter facility donated by Lockheed Corp., a private consortium called Calstart is working to create an electric vehicle industry that it hopes will utilize the engineers and other specialists idled by the aerospace industry's eight-year decline.

The goals are ambitious: a raft of sophisticated aerospace technologies harnessed for the commercial marketplace; government-industry partnerships spurring economic growth; and 55 000 new jobs by the end of the decade. In the year since its debut, Calstart has made great progress.

"We are ahead of schedule on almost every front," said Mike Gage, a former deputy mayor of Los Angeles, who recently took over command of the enterprise from Lon Bell, one of its founders.

HIGH-TECH JUDO. Calstart hopes to succeed by taking advantage of a factor that is usually cited as a weakness of California's economy—the state's stringent environmental regulations. Those regulations require, among other things, that, starting in 1998, 2 percent of all vehicles under 1700 kg sold in California—about 40 000 cars—must produce zero tailpipe emissions. The 2 percent figure rises to 5 percent just three years later, and to 10 percent, equal to 200 000 cars, by 2003.

So far, the consortium has secured almost US $20 million in funding—$14 million from industry backers and the remainder from Federal and state grants. It has already produced a showcase electric vehicle, or SEV, which has made the rounds of the big automobile shows [Fig. 1], and it has sponsored the production of an electric bus for in-city trips in the seaside community of Santa Barbara [Fig. 2].

David Lynch Contributing Editor

Yet, just six people form Calstart's salaried staff. Another 75 or so are in residence, representing member companies participating in the consortium.

Within the beige walls of its headquarters, Calstart is busy on a variety of nuts-and-bolts chores. Across California, the Los Angeles Department of Water and Power has installed 80 of a planned 140 electric vehicle (EV) charging stations, the key infrastructure element needed to make EVs viable. Most have been placed in public garages, parking lots, and corporate motor pools. Training videos also are being prepared to educate police and fire personnel on procedures for dealing with accidents involving battery-powered cars.

But while there are high hopes for this first-of-its-kind grouping of more than 40 high-tech corporations, utilities, unions, universities, and government agencies, Calstart faces an array of daunting obstacles and numerous skeptics.

For Calstart to reach its goal of 55 000 new jobs by the year 2000, it will have to capture a third of the world market in EV components. By the early years of the next century, that market will comprise annual production of about 800 000 EVs, Gage estimates. Although program officials say California's existing cadre of sophisticated aerospace designers give it a leg up in that effort, it will face numerous competitors. After all, the top auto makers in Europe, Japan, and the United States are saddled with excess plant and labor capacity.

> To create 55 000 more jobs by the year 2000, Calstart will have to capture a third of the world market in EV components

AGAINST THE FLOW. At a time when manufacturers are fleeing California's costly, regulation-ridden business climate, it is difficult to see why the advanced transportation industry should be immune. Earlier this year, concern over the state's economic prospects grew so serious that Governor Pete Wilson convened an economic summit in Los Angeles. High-level corporate and political figures came from across the state to find some way to stem the hemorrhage of manufacturing jobs.

Industry's complaints by now are familiar. California's tough air-quality regulations boost costs and slow business decisions. The state's workers' compensation system has earned national notoriety as a symbol of abuse and waste. And state political leaders until recently have appeared indifferent to the business community's concerns.

Said Richard Dore, a Hughes Aircraft Co. spokesman: "[The EV] industry has the potential to generate a lot of jobs. The question is where the jobs are going to be. But you have to be realistic. It's unlikely that will happen in California."

A 1989 plant-location study conducted for one California aerospace contractor found that the state was a far more costly place to do business than alternative sites. Average hourly wages and benefits were $17.38, compared with less than $12 for nine of 10 other states surveyed. Including administrative and overhead costs, California totaled $43.42 per hour, nearly 20 percent higher than sites in Utah and Arizona, according to the Los Angeles County Aerospace Task Force. General Motors Corp., which closed its Van Nuys car plant several months ago, said it cost almost $700 more to produce a car in California than in the Midwest.

Electric vehicle industry supporters recognize the problem and believe legislative relief from Sacramento will be needed. "Unless we do something about these problems, then everything else is just wishful thinking," said Malcolm Currie, an EV backer who moved parts of Hughes Aircraft to 17 other states when he was chairman of the defense electronics giant in the 1980s.

Currie, who stepped down from Hughes' top job in March 1992, has joined with two other principals in setting up Electric Vehicles Corp., which plans to take over some or all of the Van Nuys auto plant shuttered by GM. This veteran scientist, who helped pioneer some of the U.S. military's most advanced radars, satellites, and weaponry, appears genuinely excited about prospects for converting aging gas guzzlers into EVs in the old GM plant. "I see electric vehicles as a burgeoning new industry and I want to be a part of it," he said. "I am working twice as hard as I ever have."

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Photos: Calstart

[1] Calstart's Showcase Electric Vehicle (SEV) weighs 1200 kg, of which 380 kg is accounted for by its deep-discharge lead-acid battery. The car has a range of 160 km for stop-and-go driving. Its Peltier-effect heating and cooling system cuts its climate-control budget by a factor of five.

[2] This Calstart-sponsored 30-passenger electric bus has a range of 115 km and a top speed of 55 km/h. The vehicle is built by Bus Manufacturing USA Inc., Goleta, CA. The Santa Barbara Municipal Transit District has found its operating costs to be below those of diesel buses—even when battery replacement is taken into account.

At GM, which has placed its own electric car project on hold, executives are politely incredulous. "We are just shaking our head wondering how they are going to do all that and make a profit," said Robert Wragg, who represents GM's electric vehicle program in California.

Still, California's high costs are offset to some degree by an impressive technological infrastructure. First-rate universities, a network of advanced research facilities, and a dense cluster of aerospace suppliers stretching across the lower third of the state all make the state attractive for new high-tech ventures, Calstart's proponents say. Likewise, California is where the market for EVs will most probably get started, fueled by environmental legislation. Calstart supporters acknowledge they will need help to develop an electric vehicle industry in the state. Tax credits for consumers who purchase electric cars, as well as investment credits for companies trying to compete, are vital.

BOND ISSUE. In March, three state senators introduced an eight-part legislative package that would authorize a $100 million "clean transportation" bond measure to fund EV research and development, offer consumers rebates for purchasing EVs, and set up EV charging stations, as well as providing a range of other services.

But others are calling for bolder steps. "There needs to be a tremendous design effort from a national perspective," said Lou Kiefer of the International Association of Machinists and Aerospace Workers, which is backing Calstart. "It's going to take a moonshot effort."

High prices are expected to be the initial obstacle to widespread consumer acceptance for EVs. California residents already are eligible for a 10 percent subsidy in the form of a Federal tax credit plus a separate $1000 state tax credit on the purchase of an electric car valued up to $40 000. Gage would like the state credit to be $5000—a goal he considers achievable, given the environmental and economic pluses of a home-grown EV industry.

What Calstart is seeking is an EV in-

dustry cluster in Los Angeles, no less identifiable and self-contained than other economic groupings in Silicon Valley, Pittsburgh, Detroit, New York City, and elsewhere. According to a May 1991 study by the University of California, Los Angeles, "The goal of policies to encourage early location in Southern California is to attempt to lock the region in as the first comer in a large-scale electric vehicle industry."

Proponents say an EV industry is likely to emerge first through the efforts of small, second-tier high-tech companies that will supply components to the Big Three car makers. Some in Detroit believe Calstart's ultimate aim is production of an entire car to compete with GM, Ford, and Chrysler. But consortium officials deny that is the case.

Operating as a clearinghouse for information and technical interchange, Calstart intends to act as a catalyst in speeding commercialization of surplus aerospace expertise. Several aerospace companies—Hughes, Aerojet General, ITT Cannon, and Dowty Aerospace in Los Angeles—are working with Calstart, conscientiously attempting to merchandise the state's rich harvest of aerospace technologies.

MILITARY CONNECTION. As if to make the point, consortium brochures show an SR-71 spy plane metamorphosing into the Calstart showcase electric vehicle. "We want to take advantage of the huge investment in defense and aerospace in this state," said Gage. "We want to tap the intellectual capital."

Since World War II, when Detroit's auto plants were among the first to shift to production of war materiel for the Allies, a synergy has existed between the auto and defense industries. But the nature of that relationship has changed in recent years.

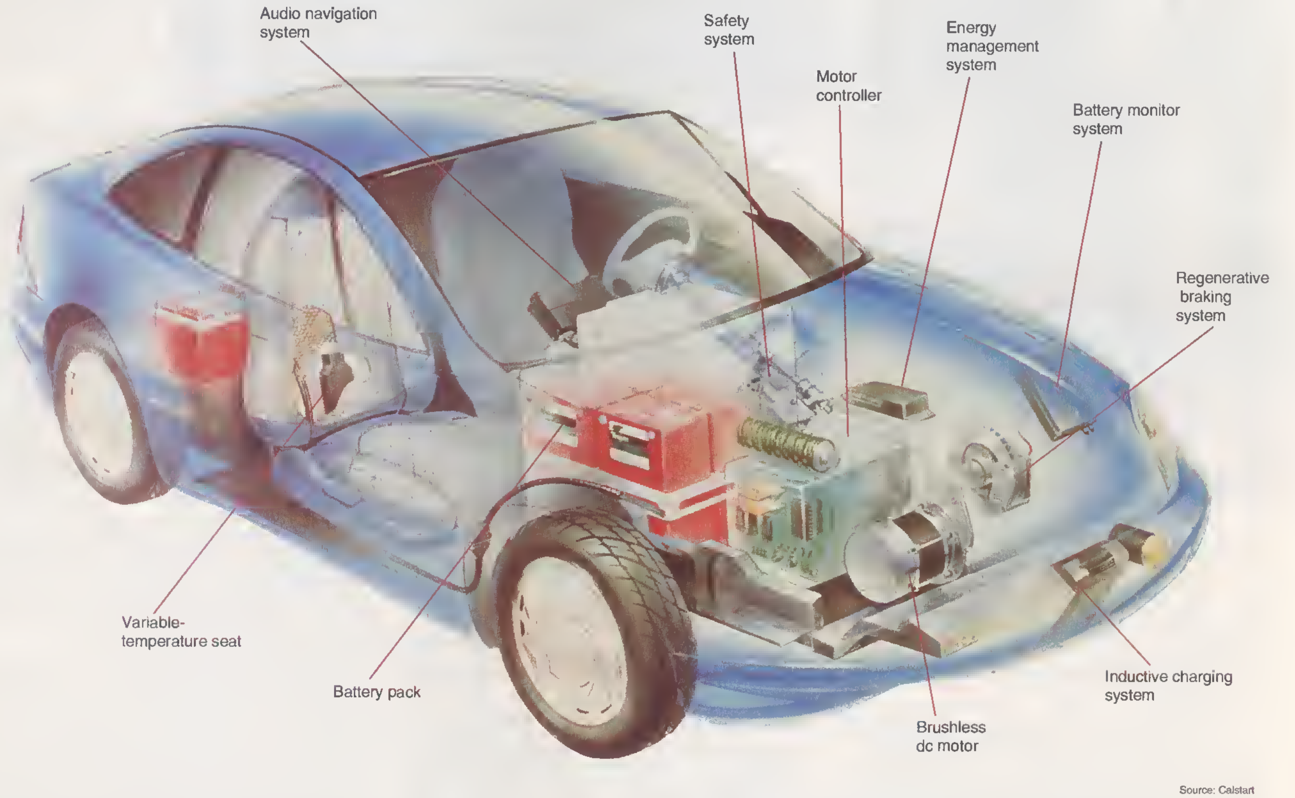
Now Calstart is betting that an EV industry will have more in common with the high-tech end of California's aerospace sector than with the conventional auto components churned out by the Big Three. Advanced materials, lightweight design, electronics, and energy storage devices are areas in which the consortium perceives opportunity.

At Hughes Aircraft, engineers have made steady progress with prototypes of the chargers consumers will use to charge their EV batteries. One year ago, early models were operating at 6 kW. Hughes recently demonstrated a 25-kW model to corporate parent General Motors. By year's end, 100 kW is the target, with fully "productionized" 25-kW models outfitted to accept credit card purchases entering mass production, according to Hughes' program manager Troy Nestor.

Indeed, through its corporate links with GM, Hughes already boasts an excellent track record of transferring defense technology to civilian applications. In the late 1980s, Hughes adapted a head-up display it had developed for Air Force fighter aircraft for use in GM's passenger cars. The version Hughes sold the Pentagon cost almost $400 000. But after years of painstaking development, the company produced a stripped-down commercial model that GM offered consumers for $150, according to former Hughes executive Currie.

Throughout Calstart's prototype operation, aerospace experience is producing mini-breakthroughs. The passenger seats in the showcase electric vehicle, for example, are individually heated and cooled using Peltier junction technology originally developed for the sidewinder missile. By simply reversing the polarity of the current flowing through the Peltier junctions, the system switches from heating to cooling. The technique increases the efficiency of the vehicle's climate control system by concentrating its effects in the automobile's seats, directly heating and cooling the passengers, while expending only a little energy on the passenger compartment itself [Fig. 3].

According to Lon Bell, now president of Amerigon Inc., Monrovia, CA, which designed the system, a little heated air blowing



[3] The showcase electric vehicle serves as a test bed for a wide variety of innovations, some of which may benefit conventionally powered vehicles. For example, its variable-temperature seats can cool passengers with only 20 percent of the usual energy expenditure. (It can also heat them very efficiently, a boon to EVs but not to conventional vehicles, which are warmed at essentially no cost by waste engine heat.) Similarly, its audio navigation system "speaks" replies to spoken requests for help in reaching destinations, so that the driver may operate the system without taking her eyes off the road. After calculating the best route, the system instructs the driver to follow that route, one leg at a time, complete with distances to be covered and estimates of the time required.

out of the vents, combined with heating of the seats, combines a high degree of passenger comfort with a great saving of energy. For cooling, he told *IEEE Spectrum*, the technique has so far proved less satisfactory. Some passengers find it quite acceptable; others, less so.

REALITY CHECK. But whether the emerging ties between some aerospace companies and Calstart suggests dramatic new employment opportunities for excess aerospace engineers, managers, and production workers remains in doubt. The sheer scale of the aerospace downturn is likely to swamp Calstart's efforts—or any single conversion strategy, for that matter. By one estimate, 60 000 aerospace jobs disappeared in California between 1986 and 1991. Another 50 000 will be gone by year end, with tens of thousands more to follow.

Against that employment drain, Calstart's 55 000-job goal—while ambitious for a fledgling industry—offers little immediate hope for many. Doubts have been raised as to whether EV production will require anything like the number of jobs forecast. Before General Motors pulled the plug on its Impact electric vehicle late last year, it had drawn up plans to add just 250 jobs to its Lansing, MI, facility to support production for tens of thousands of Impacts, according to Robert Wragg.

Moreover, even if Calstart reaches its goal five to seven years from now, that still begs the question of what happens to aerospace engineers in the interim. Some experts foresee a slow drain of California's engineering talent to other locales. "The scale of the solution doesn't fit the scale of the problem," said Robert Paulson, who tracks the aerospace industry for McKinsey & Co. in Los Angeles. "It's [minute] compared to the layoffs in California."

Calstart's current training efforts are targeted more at positioning existing companies to compete for EV work than at equipping laid-off workers with new skills. The 30 aerospace veterans now being trained by Calstart in the ways of the auto industry all have jobs with Los Angeles-area aerospace companies and Calstart sponsors Dowty, Group IX Systems, and Amerigon.

At the end of the three-month program, the trainees will fan out into their companies and train their co-workers in the rigorous demands of the commercial marketplace. Said Josh Newman, who directs Calstart's training: "We are working with the companies themselves who are interested in making this transition. We are not interested in training people who are unemployed."

ATTITUDE ADJUSTMENT. In working for the automotive industry, aerospace engineers will be facing a big adjustment. The low-volume, high-cost world of defense work could not be further removed from the dog-eat-dog world of commercial automobile manufacturing. The highly formalized government procurement process revolves around inch-thick contract solicitations that draw similarly dense responses from industry.

Hughes Aircraft Co.

[4] When a focus group concluded that consumers did not like the annular shape of Hughes' induction charging unit, the company was quick to fill the hole in the doughnut, producing a paddle-like device [inset].

In contrast, the high-volume commercial market is much less structured, and its main emphasis is on minimizing costs. Experts differ on how rough the transition will be, but all agree that retraining of aerospace industry personnel will be needed—for middle managers as well as engineers .

Since Calstart is deliberately trying to make use of aerospace technology, the key problem for program engineers is not acquiring new technical skills but learning marketing know-how. Hughes has tried to address this issue by inviting engineers working on its battery charger to attend consumer focus groups. "At first, I was afraid none of them would attend," said Troy Nestor, Hughes' program manager. "In the end, I had to turn some away."

The Hughes teams received an early lesson in the difficulty of predicting consumer response when they tested a doughnut-shaped, handheld charger. Consumers almost uniformly said that the device, which represented the ideal engineering solution, felt flimsy. Hughes responded by filling in the doughnut's hole, producing a paddle-like charger, with which customers felt more comfortable [Fig. 4].

Gage pointed out that Calstart cannot be the sole solution to California's conversion challenge. He envisions a host of similar consortia promoting new state industrial clusters in environmental technologies, state-of-the-art media, and telecommunications. A conscious goal of those working to reorient the battered and bruised Golden State economy is to avoid previous generations' excessive vulnerability to downturns in a single industry. California would "be better off with a more diversified base," Gage said.

Seemingly, the skeptics are having little impact on Currie or Gage or the other Calstart enthusiasts. After a chance meeting at a recent Los Angeles luncheon, Gage is hoping for a visit from Transportation Secretary Federico F. Pena later this year. But most of all, he is looking forward to the day his services and those of Calstart are no longer needed.

Said Gage: "My goal is to put Calstart out of business by the year 2000." ◆

ABOUT THE AUTHOR: David Lynch is a reporter for the Orange County Register *in Santa Ana, CA, covering aerospace activities.*

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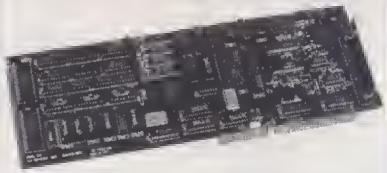

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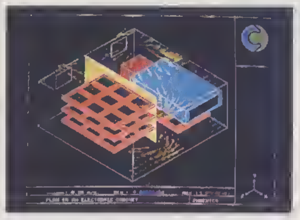

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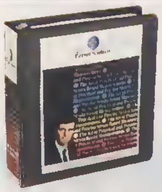

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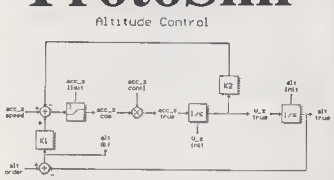

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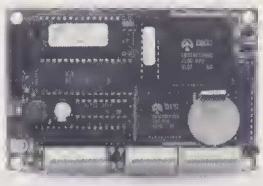

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Recent books

(Continued from p. 16)

Computer Systems for Automation and Control. *Olsson, Gustaf,* and *Piani, Gianguido,* Prentice Hall, Englewood Cliffs, NJ, 1992, 428 pp., $41.95.

Visualizing Software: A Graphical Notation for Analysis, Design, and Discussion. *Bennett, William S.,* Marcel Dekker, New York, 1992, 208 pp., $35 (on orders of five or more copies, for classroom use only), $79.95 (regular price).

Spiral Vector Theory of AC Circuits and Machines. *Yamamura, Sakae,* Oxford University Press, New York, 1992, 132 pp., $67.50.

Client/Server Computing. *Smith, Patricia, et al.,* SAMS/Prentice Hall, Carmel, IN, 1992, 341 pp., $49.95.

Transformation Methods for Nonlinear Partial Differential Equations. *Edelen, Dominic G. B.,* and *Wang, Jian-hua,* World Scientific Publishing Co., River Edge, NJ, 1992, 325 pp., $58.

Model Reference Adaptive Control. *Butler, Hans,* Prentice Hall, Englewood Cliffs, NJ, 1992, 265 pp., $60.

MVS I/O Subsystems: Configuration Management and Performance Analysis. *Houtekamer, Gilbert E.,* and *Artis, H. Pat,* McGraw-Hill, New York, 1993, 419 pp., $49.95.

The Whole Internet User's Guide & Catalog. *Krol, Ed,* O'Reilly & Associates, Sebastopol, CA, 1992, 400 pp., $24.95.

Enterprise-Wide Networking. *Schnaidt, Patricia,* SAMS/Prentice Hall, Carmel, IN, 1992, 493 pp., $39.95.

Plasma Technology: Fundamentals and Applications. Eds. *Capitelli, Mario,* and *Gorse, Claudine,* Plenum Publishing, New York, 1992, 224 pp., $65.

Que's 1993 Computer Buyer's Guide. *Smith, Bud,* Que/Prentice Hall, Carmel, IN, 1992, 432 pp., $16.95.

Atmospheric Ultraviolet Remote Sensing. *Huffman, Robert E.,* Academic Press, San Diego, CA, 1992, 320 pp., $59.95.

Acousto-Optic Devices: Principles, Design and Applications. *Xu, Jieping,* and *Stroud, Robert,* John Wiley & Sons, New York, 1992, 652 pp., $69.95.

Op-Amps and Linear Integrated Circuits, 3rd edition. *Gayakwad, Ramakant A.,* Prentice Hall, Englewood Cliffs, NJ, 1993, 640 pp., $54.67.

Systems & Control Encyclopedia, Supplementary Vol. 2. Ed. *Singh, Mandan G.,* Pergamon Press, New York, 1992, 1087 pp., $390.

Linear System Theory. *Rugh, Wilson J.,* Prentice Hall, Englewood Cliffs, NJ, 1993, 356 pp., $56.

Remote Sensing by Fourier Transform Spectrometry. *Beer, Reinhard,* John Wiley & Sons, New York, 1992, 153 pp., $74.95.

Programming Windows 3.1. *Petzold, Charles,* Microsoft Press, Redmond, WA, 1992, 1008 pp., $49.95.

The Windows Interface: An Application Design Guide. *Microsoft Corp.,* Microsoft Press, Redmond, WA, 1992, 248 pp., $39.95.

Exploiting Cycle Time in Technology Management. *Gaynor, Gerard H.,* McGraw-Hill, New York, 1993, 348 pp., $46.50.

Microsoft PowerPoint for Windows: Step by Step, Version 3. *Johnson, Steve,* Microsoft Press, Redmond, WA, 1992, 328 pp., $29.95.

Engineer at large

No child support, no professional license

Searching for new ways to collect unpaid child support money, a growing number of states are looking to revoke the professional licenses of engineers and others who miss support payments. According to an article in *Engineering Times* (May, p. 1), published by the National Society of Professional Engineers (NSPE), the states of Arizona, California, Minnesota, Montana, South Dakota, and Vermont have laws permitting revocation of professional licenses, and 20 other states are considering similar measures. Also, lawmakers in the U.S. House of Representatives and Senate introduced a comparable provision in the Interstate Child Support Enforcement Act, now under consideration.

NSPE's Registration and Qualifications for Practice Committee, however, plans to recommend that the society's board of directors adopt a policy statement opposing laws that tie professional licensure to legal issues such as child support payments, tax disputes, student loan repayments, and substance abuse. The proposed statement argues that such laws create "a wholly unrelated and arbitrary standard" for judging a [professional engineer's] fitness to practice" and, because it targets only professional license holders, denies them equal rights under the law.

Rolex Award for plan to monitor ozone

A resident of Seguin, TX, who has spent his career inventing electronic instruments and writing about electronics in popular scientific magazines, has won a Rolex Award for Enterprise. He not only designed and built an affordable instrument for measuring the ozone layer—he has also organized a network of people who will use it in unlikely spots around the world.

For those feats, Forrest M. Mims III (A) was given 50 000 Swiss francs and a gold Rolex chronometer by watchmaker Montres Rolex SA of Geneva, Switzerland.

Mims's total ozone portable spectroradiometer (TOPS) calculates the thickness of the ozone layer by measuring the intensity of the ultraviolet radiation that reaches the earth after passing through the atmosphere. Initially, he plans to build 25 of his US $500 handheld instruments and distribute them to members of his network, which includes explorers, scientists, naturalists, and adventurers traveling to distant climes.

The plan is for them to use Mims's instruments to measure total ozone, direct solar ultraviolet radiation, and atmospheric turbidity in places remote from official data-collection stations, such as mountain peaks, and in both equatorial and polar regions that have suffered high ozone depletion.

Applicants for his network came from 18 countries, he told *IEEE Spectrum*. "Half are professional scientists with Ph.D.s, who couldn't otherwise get such an inexpensive instrument," he said.

Granted first in 1978 and every third year thereafter, the Rolex awards pay tribute to "those whose passionate pursuit of a

Engineer at large

dream has inspired them to develop projects in the fields of applied sciences and invention, exploration and discovery, and the environment," according to André J. Heiniger, who spoke on April 30 in Geneva as he presented this year's awards to five individuals.

As it happened, the only other award for an engineering accomplishment also had to do with the ozone layer, albeit indirectly. Steven L. Garrett, an expert in thermoacoustics and professor of physics and space systems engineering at the Naval Postgraduate School, Monterey, CA, was chosen for his development of a novel refrigeration system. Instead of the ozone-hostile chlorofluorocarbons used in most such equipment, Garrett relies on high-intensity sound to transfer heat. [See also Innovations, June, p. 16.] A prototype was tested on board the space shuttle Discovery in 1992, with good results, according to the Rolex announcement.

Graduate energy studies listed

The first *Directory of Energy-Related Graduate Programs in U.S. Universities* is available free of charge through the Energy Foundation in San Francisco. The directory describes more than 60 programs in the fields of energy, resources, environment, and development.

For a paper or disk copy of the directory, contact Directory Offer, *Home Energy* Magazine, 2124 Kittredge St., No. 95, Berkeley, CA 94704; 510-524-5405.

Doctors in integrated manufacturing

The National Research Council in the United States has picked 12 people for its first predoctoral fellowship program in integrated manufacturing. Each award carries an annual stipend of $20 000 and an education allowance of as much as $15 000 for three years.

The program has the threefold objective of creating a pool of Ph.D.s trained in the integrated approach to manufacturing, promoting academic interest in the field, and attracting talented professionals to a challenging area of engineering.

Other goals of the program are to develop more energy-efficient manufacturing methods, devise better ways to make use of scarce resources, and curb environmental degradation.

Those chosen must have, or be close to having, their master's degrees and must outline a research program they wish to pursue. The program is funded by the Department of Energy's Office of Basic Energy Science-Engineering Research Program.

Information and application materials for next year's awards will be available after Sept. 1. Write to or call the Fellowship Office, National Research Council, 2101 Constitution Ave., N.W., Washington, DC 20418; 202-334-2872.

Computer science for deserving fellows

The Alfred P. Sloan Foundation has added computer science to the fields in which it backs research carried out by young academics. The first eight fellowships are to be awarded in 1994.

September 15 is the deadline for nominations. Direct applications are not accepted by the foundation.

The Sloan Research Fellowships in computer science are intended to provide flexible research support to promising young faculty members at an early stage in their careers.

For information and nomination forms, write to Sloan Research Fellowships, Alfred P. Sloan Foundation, 630 Fifth Ave., Suite 2550, New York, NY 10011.

COORDINATOR: Alfred Rosenblatt

EEs' tools & toys

Museum gallery explains machine intelligence

"Robots & Other Smart Machines" is a permanent gallery at Boston's Computer Museum dedicated to teaching visitors what smart machines can and cannot do. The interactive gallery features 25 notable robots, including the National Aeronautics and Space Administration's original Mars Land Rover and the robot arm developed by Marvin Minsky, of the Massachusetts Institute of Technology, who is often described as the father of artificial intelligence.

In addition to the robots, the gallery illustrates a wide variety of other artificial-intelligence applications at its 30-odd computer stations. Among them: computer-generated music and drawings, computer-generated speech with "real feeling," and efficient-kitchen design.

Summer hours at the Museum are from 10 a.m. to 6 p.m. seven days a week. Admission is US $7 for adults and $5 for children and seniors. Children under 4 years of age pay nothing. *Contact: The Computer Museum, 300 Congress St., Boston, MA 02210; 617-426-2800; fax, 617-426-2943; or* **circle 105.**

DIGITAL SIGNAL PROCESSING

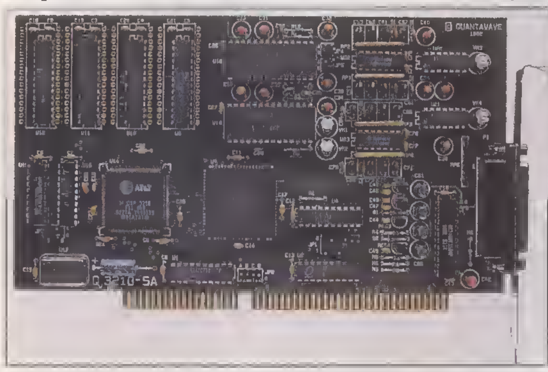
Simpler signal analysis

As growing numbers of engineers and scientists realize the advantages of digital signal processors (DSPs), the number of first-time users of those products is increasing. Recognizing that those new users need all the help they can get in programming their DSPs, Quantawave has taken especial care with the user's manual for its Qw3210-SA signal analysis board, and has also bundled the board with software that lets users bypass part of the learning curve associated with most other such products.

The bundled software includes a C interface library and a resident monitor that works in tandem with the library. The library, which is compatible with DOS and Windows 3.X, includes DSP program downloading and execution, high-speed data transfer between the Qw3210-SA and its host PC, and several debugging features. The resident monitor performs all necessary hardware setup. It also provides task-switching services, a mechanism for passing parameters between tasks, error reporting, and breakpoint capability.

The Qw3210-SA board itself is an ISA-bus device based on the AT&T DSP3210 chip. It has two instrumentation-quality analog input channels and two analog output channels, in addition to its eight digital I/O lines. Both analog inputs have a programmable-gain instrumentation amplifier and an a-d converter that digitizes inputs at a rate of 200 kilosamples per second with a resolution of 16 bits. The board comes standard with 136 kB of high-speed static RAM, expandable to 2 MB.

The Qw3210-SA is priced at $2995 in singles, with steep discounts available for quantities of two or more. (Discounts start at 5 percent for two boards, and climb to 60 percent for 100 or more.) *Contact: Quantawave, 530 Boston Post Rd. East, Marlborough, MA 01752-3645; 508-481-9802; fax, 508-624-0942;* **or circle 106.**



Quantawave

Built around the AT&T DSP3210 digital signal-processing chip, Quantawave's Qw3210-SA signal analysis board features an instrumentation-quality analog front end. It has two 16-bit input channels, each capable of 200 kilosamples per second.

EDUCATION

Lexicons worth looking at

The Institute recently announced the availability of two new technical dictionaries: the fifth edition of its own *Standard Dictionary of Electrical and Electronics Terms,* and the International Electrotechnical Commission's *Multilingual Dictionary of Electricity, Electronics and Telecommunications.*

The IEEE dictionary now contains detailed abstracts of IEEE standards in addition to more than 30 000 terms from every field of electrical, electronics, and computer engineering. It also has an extensive section of acronyms and abbreviations, including many popular TLAs (three-letter acronyms).

The IEC dictionary provides English definitions for more than 15 000 terms that are given in nine languages: Dutch, English, French, German, Italian, Polish, Russian, Spanish, and Swedish.

The IEEE dictionary is priced at $90 for nonmembers, $63 for members. The IEC publication lists for $185, but is offered to IEEE members for $129.50. A brochure that gives details on both dictionaries is available. Note: The IEEE handles the IEC multilingual dictionary only in North America. Readers who reside elsewhere can order that publication from Elsevier Science Publishers, Book Order Department, Box 211, 1000 AE Amsterdam, The Netherlands; (31+20) 580 3753; fax, (31+20) 580-3705. *Contact: IEEE Standards, Box 1331, Piscataway, NJ 08855-1331; 908-562-3824; or* **circle 107.**

Technology being given away

The U.S. government has a policy of encouraging companies to develop products based on work done under Federal research programs. To help companies learn about such work, the National Technology Transfer Center (NTTC) has been operating a telephone inquiry service that conducts information searches upon request.

Now, to speed the process, the NTTC is augmenting its gateway telephone service with an electronic bulletin board through which any U.S. company may access the NTTC database at no cost (except for the price of the phone call).

The service should be operational by June 30—about the time this issue hits the street. *Contact: National Technology Transfer Center, Wheeling Jesuit College, 316 Washington Ave., Wheeling, WV 26003; 304-243-2455; fax, 304-243-2463; or* **circle 108.**

INSTRUMENTATION

Multiwire clamp-on ammeter

The use of clamp-on ammeters for measuring current without breaking a circuit is well established, but only for single current-carrying conductors. Now ElectraScan Inc. is offering a clamp-on probe for two- and three-wire cables.

Called the Model VIP-100, the probe snaps over Romex and other cable types and determines how much current is flowing by sensing the leakage magnetic field surrounding the cable. It connects to any modern ac multimeter in order to provide a scaled reading of the current.

Tools & toys

The VIP-100 is factory calibrated to read 1 millivolt per ampere for standard 12-2 Romex cable, but may be recalibrated in the field for other cable types. It works from 0 to 100 A over the frequency range of 15 Hz to 100 kHz.

The probe is priced at $97.50; delivery is from stock. *Contact: Electrascan Inc., 2917 Avalon Ave., Berkeley, CA 94705; 510-548-3358; fax, 510-548-1878; or* **circle 109.**

Bargains in data acquisition

Keithley Data Acquisition has bundled several of its hardware and software products together and is offering them at discount prices through Aug. 31. The products are described in a special Classic Values catalog, which also includes software packages from other software companies. Those packages, like Labtech Notebook and DriverLinx, are also offered at reduced prices if they are purchased in combination with Keithley data-acquisition boards.

Keithley

Keithley's Classic Values catalog includes combinations of data-acquisition boards and software at substantially reduced prices. The discounts are valid through Aug. 31, 1993.

The savings offered are substantial. For example, the combination of the DAS-1600 board and Easyest LX software is being offered for $1194, which is $400 less than the cost of the two items separately—a saving of more than 25 percent.

The catalog is available free of charge. *Contact: Keithley Data Acquisition, 440 Myles Standish Blvd., Taunton, MA 02780; 800-348-0033; or* **circle 110.**

COMPONENTS

Reducing battery maintenance

Although commonplace, charging and discharging lead-acid storage batteries is not without its problems. The batteries give off hydrogen, which can be explosive in enclosed areas. Watering can be inconvenient, especially for photovoltaic systems, which are often built in remote locations. And corrosion is always a danger.

These difficulties can be mitigated through the use of Hydrocap vents—catalytic battery caps that combine emitted hydrogen gas with oxygen and return the resultant water to the battery cell. In returning water to the battery cells, the caps wash acid spray and fumes back into the cells, thereby reducing the corrosion of metal around the battery.

The vents are manufactured by Hydrocap Corp. in accordance with customer specifications. The company offers almost a thousand combinations of body sizes, threaded adaptors, and Catylator units. The caps typically cost $5.25 to $5.50 apiece. *Contact: Hydrocap Corp., 975 N.W. 95 St., Miami, FL 33150; 305-696-2504; or* **circle 111.**

SOFTWARE

Interactive handbooks

For those who want to keep references digitally close at hand, MathSoft has introduced two $99 electronic handbooks. *Topics in Mathcad: Advanced Math* illustrates a variety of problem-solving techniques and provides the general-purpose tools needed. Included are iterative ways of solving differential equations, eigenvalues, and matrix operations, as well as ways to use fast Fourier transforms.

A second title, *Topics in Mathcad: Electrical Engineering,* contains 24 documents, each with a background section describing the physics or mathematical aspect of the problem and an annotated description of the solution. Some of the applications discussed are electromagnetism, circuit theory, signal processing, and filter design.

The references run under MS-DOS 3.X or higher, Windows, Mac OS 6.05 or later, and the popular Unixes. They require Mathcad 3.1 or higher and about 4–6 MB of hard-disk space, depending on configuration. *Contact: MathSoft Inc., 201 Broadway, Cambridge, MA 02139-1901; 800-628-4223; or* **circle 112.**

Seeing optical properties

Based on a database and algorithms under development since 1988 by the Electro-optical Systems Group of the John Hopkins University/Applied Physics Laboratory and ARSoftware Inc., Optimatr is a PC application that provides the optical properties of a wide variety of materials used in electro-optics. Among the substances covered are germanium, silicon, sapphire, diamond, and gallium arsenide, as well as those materials typically used for optical-bench windows, lasers, and lenses.

Serving as a handy reference, the program calculates the absorption coefficient, index of refraction, and scattering coefficient for over 100 types of crystals, dielectrics, semiconductors, metals, and glass. Users specify the wavelength range of interest, the desired step size, and the temperature in Kelvin to be used in determining those parameters, and then hit C to calculate. (Alternatively, the wave number may be specified instead of the wavelength.)

While the parameters are being calculat-

To help semiconductor researchers be as effective as possible, the Semiconductor Research Corp. (SRC) has for the past two years put out a directory of key faculty engaged in semiconductor research. It is now in the process of gathering data for its third directory, for publication next January.

The new directory will include all full-time faculty in Canada as well as a larger number of people in the United States whose work is not sponsored by the SRC.

To gather names for the updated version, the SRC is surveying full-time faculty from June through September, requesting those engaged in semiconductor research to fill out a one-page questionnaire about their research activities and interests. For purposes of the survey, "semiconductor research" includes research on devices, design, process technology, manufacturing systems, packaging, and reliability. The third Semiconductor Research Faculty Profile will consist of both a computer database and a bound directory.

Researchers included in the second edition of the directory will automatically be mailed a questionnaire for updating. Subscribers to the *SRC Newsletter* will find a questionnaire printed in the August issue. Others who think they should be listed in the new directory may obtain a questionnaire free of charge from the SRC. *Contact: The SRC Faculty Profile, Semiconductor Research Corp., Box 12053, Research Triangle Park, NC 27709; 919-541-9400; fax, 919-541-9450; or* **circle 114.**

COORDINATOR: Michael J. Riezenman
CONSULTANT: Paul A.T. Wolfgang, Boeing Defense & Space Group

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While the parameters are being calculat-

ed, the screen presents the names of the mathematical models being used. For determining absorption coefficients, the models provided are the one photon and free carrier, the multiphoton, and the Urbach tail. For accurate calculation of the index of refraction at room temperature, there is the Sellmeier model, and scatter is determined using Rayleigh (intrinsic) and Mei (extrinsic) equations. If an experienced optical practitioner wishes, he or she may edit these models or the material database.

The program runs on an 80X86 IBM-compatible PC with an EGA/VGA card under MS-DOS 3.1 or higher. And while the program can emulate floating-point operations, a math coprocessor is recommended. Until July 31, Optimatr is priced at \$495; after that the list price will rise to \$695. *Contact: ARSoftware Inc., 8201 Corporate Dr., Suite 1110, Landover, MD 20785; 800-257-0073; fax, 301-459-3776; or* **circle 113.**

SOLID STATE

Getting listed for chip research

To help semiconductor researchers be as effective as possible, the Semiconductor Research Corp. (SRC) has for the past two years put out a directory of key faculty engaged in semiconductor research. It is now in the process of gathering data for its third directory, for publication next January.

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The following listings of interest to IEEE members have been placed by educational, goverment, and industrial organizations as well as by individuals seeking positions. To respond, apply in writing to the address given or to the box number listed in care of *Spectrum* Magazine, Classified Employment Opportunities Department, 345 E. 47th St., New York, N.Y. 10017.

ADVERTISING RATES

Positions open—$36.00 per line, not agency-commissionable

Positions wanted—$36.00 per line, a 50% discount for IEEE members who supply their membership numbers with advertising copy.

All classified advertising copy must be received by the 25th of the month, two months preceding the date of issue. No telephone orders accepted. For further information call 212-705-7578.

IEEE encourages employers to offer salaries that are competitive, but occasionally a saslary may be offered that is significantly below currently acceptable levels. In such cases the reader may wish to inquire of the employer whether extenuating circumstances apply.

Academic positions open

Department of Electrical and Computer Engineering (ECE), Ohio University: Applications are invited for a junior level, tenure-track position with an avionics interest. Duties will include teaching at both the graduate and undergraduate levels, developing and teaching avionics-related courses, promoting and participating in avionics-related research, and directing research of graduate students in the avionics area. ECE offers both the M.S. and the Ph.D. degrees. The department is composed of an academic unit with 21 full-time faculty and a research unit, the Avionics Engineering Center (AEC), with a staff of more than 25. The person holding this position will be expected to conduct and promote research under the auspices of the AEC. Applicants must have a Ph.D. or equivalent degree in electrical engineering. The AEC is a unique organization that specializes in research and engineering related to safety in take-off, landing, and navigation phases of flight. Research topics in AEC include ILS, MLS, GPS, LORAN, VOR, radio frequency interference and communications. The present external support of the AEC exceeds $3.0M per year. The AEC has excellent research equipment and facilities, including two instrumented aircraft and a recently built hangar worth more than $1M. The department and college have a wide range of computing equipment, including SUN workstations and IBM-compatible personal computers. Applications will be accepted until the position is filled. Send resume and names of at least three references to Dr. Jerrel R. Mitchell, Chairman, Electrical and Computer Engineering, Stocker Center, Ohio University, Athens, OH 45701-2979. Ohio University is an equal opportunity and affirmative action employer.

Princeton University: The Department of Electrical Engineering invites applications for a full time tenure-track faculty position in the area of optics and advanced photonic materials, devices or systems. Materials, devices or architectures work should concentrate on their application to ultra high bandwidth or high density photonic systems. Examples include semiconductor lasers, ultrahigh bandwidth integrated circuits, III-V and II-VI photonic device fabrication and characterization, optoelectronic integrated circuits, integrated optics, optical/materials interactions, photorefractive and nonlinear optical materials and devices, and optical architectures including computers, neural nets, signal processors, etc. Candidates should have a desire for working in a group environment on collaborative projects with new scientific objectives and content. Please send a complete resume, a description of research and teaching interests, and names of three references to Professor Stuart Schwartz, Chair, Dept. of EE, Princeton University, Princeton, NJ 08540-5263. Princeton University is an equal opportunity/affirmative action employer.

Industrial Research Chairs in Instrumentation & Control. In anticipation of the establishment of Industrial Research Chairs in Advanced Instrumentation and Control, the Faculty of Engineering at the University of New Brunswick is inviting applications from highly qualified individuals. The industrial partner with the University is Monenco-AGRA, a highly respected firm in engineering and contracting. It is anticipated that these Chairs will be in place in early 1994. The appointments, which are tenure track, will be for a Senior and a Junior Chair. One of these appointments will be in Electrical Engineering. Qualified candidates from any engineering discipline will be seriously considered. High academic qualifications, industrial experience and willingness to collaborate with industry will be major factors in candidate selection. The Faculty of Engineering has programs in place in the areas of performance monitoring and fault diagnosis, smart sensors and actuators, real time data acquisition, simulation, and robust control design. In addition, cooperation will be expected with existing Industrial Research Chairs such as Nuclear Engineering and Pulping Technology as well as with the Power Plant Engineering Practice Chair. Candidates must have a PhD with a strong applied research background in control and instrumentation. Industrial experience is mandatory. The Senior Chair will have an established international reputation. The Junior Chair will be an established research performer with appropriate experience and a developing career. Full collaboration with Monenco-AGRA and other industrial sponsors must be a commitment of the selected candidates. An important goal of the Chairs will be the transfer of technology to industry. The University of New Brunswick is committed to the principle of employment equity. In accordance with Canadian Immigration requirements, priority will be given to Canadian citizens or permanent residents. The closing date for nominations and applications will be September 1, 1993, or until the position is filled. Nominations, applications and requests for information should be forwarded to: Dr. Wolfgang Faig, Dean, Faculty of Engineering, University of New Brunswick, P.O. Box 4400, Fredericton, NB Canada E3B 5A3. Fax: 506-453-4569.

The Electrical Engineering Department at Tuskegee University invites applications for several tenure-track faculty positions at the Assistant and Associate Professor levels beginning Fall 1993 semester in the areas of communications, VLSI systems, signal processing, solid-state microelectronics, electronic materials and computer engineering. Candidates must have an earned Ph.D. in Electrical Engineering and should have demonstrated potential for teaching and development of research in his/her area of specialty. Also, candidates should show a strong commitment to the professional development of African Americans. Send resume and names of three references to: Office of the Dean, School of Engineering and Architecture, Tuskegee University, Tuskegee, Alabama 36088. Ph: (205) 727-8355. Tuskegee University is an equal opportunity/affirmative action employer.

The Chinese University of Hong Kong invites applications to faculty positions in all areas related to communication technologies. Please send full resume, names of at least three references, and a brief research plan to Chairman, Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong. For inquiry, e-mail: tsyum@ie.cuhk.hk.

Assistant Professor, Electrical Engineering Technology; 40 hrs./wk, 9am-5pm; Sal: $34,700 per yr; teach Control Systems, Electronic Device Applications, & Fundamentals of Electronics; supervise students' project for design, compiling & programming of computer programmable chip array logic according to design; draft curriculum materials for teaching of Very Large Scale Integrated Circuits (VLSI), incl. principles of design & chip fabrication of complex circuit for purposes of utilizing capabilities in "state of the art" semiconductor computer devices. Reqs: MS in Electrical Engineering incl. 3 credit hr. courses in Digital System: Memory & Interface, VLSI, & Advanced, VLSI System Design using CMOS (Complementary Metal Oxide Semiconductor). Proof of legal authority to work indefinitely in U.S.A. Send resume in duplicate (no calls) to J. Davies, JO# 1333275, Ohio Bureau of Employment Services, PO Box 1618, Columbus OH 43216.

Grad Student Ph.D. Assistantships open for only highly experienced engineers in the power quality area. Send resume with refs and GRE to Dr. Alex Domijan, Director, Florida Power Affiliates, Dept. of Electrical Engineering, Univ. of Florida, 323 Benton Hall, Gainesville, FL 32611, (904)392-0290.

Assistant/Associate Professor. The Department of Electrical Engineering is seeking applications for tenure-track faculty position starting in Fall 1993. Applicant should have a Ph.D degree in Electrical Engineering and/or Computer Engineering. Main areas of interest include Computer Engineering with emphasis in hardware and software, and microcomputer applications or computer networking, Signal/Image Processing, Wavelets and Neural Networks, or Control Systems and Robotics, with emphasis on applications. Salary range will be $39,000 - 42,000. Responsibilities include teaching graduate and undergraduate courses in areas of specialization. Develop related laboratories, advise and supervise student design projects, attract and execute funded research, generate refereed publications and promote public service. Applications containing a recent resume should be sent to Tennessee State University, Personnel Office, 3500 John Merritt Blvd., Nashville, TN 37209-1561 by July 10, 1993. TSU is an equal opportunity/affirmative action employer.

The Department of Electrical Engineering and Applied Physics of the Oregon Graduate Institute of Science & Technology is interested in receiving applications for several new faculty positions in the department. Primary attention will be given to applicants at the assistant professor level, however, applications at higher levels will be considered based on expertise and qualifications. A Ph.D. in electrical engineering or related field is required. Areas of consideration include: i) Telecommunications, ii) Digital Signal Processing with emphasis on multimedia applications, iii) Adaptive Systems and, iv) VLSI design. Successful candidates will need to have a proven record of academic accomplishments including teaching and course development, publications in reviewed journals, activity in their professional expertise and a strong record of success in funded research in their relevant area. Duties will include teaching and department services, as well as funded research. The individual is expected to build a strong externally funded research program. Interested persons should submit a complete resume and names of three references to: Dr. Thomas W. Sigmon, Douglas Strain Professor and Department Head, Department of Electrical Engineering and Applied Physics, Oregon Graduate Institute of Science & Technology, 20000 N.W. Walker Road, P.O. Box 91000, Portland, OR 97291-1000. Affirmative Action/Equal Opportunity Employer.

University of Hawaii at Manoa, Department of Electrical Engineering, invites applicants for a tenure-track associate professor or assistant professor position with specialization in Computers: Advancement of knowledge and state of the art in high performance computing systems, image understanding or parallel and distributed algorithms. Duties: Teach EE undergraduate and graduate courses, serve on university and department committees, conduct research and scholarly activities, and perform related tasks as

assigned. Minimum Qualifications: Associate Professor: Ph.D. degree in electrical engineering, computer science, or equivalent; minimum of four years of full-time college or university teaching at the rank of assistant professor or equivalent, with evidence of increasing professional maturity; demonstrated scholarly achievement in comparison with peers active in the same field; demonstrated ability to plan and organize assigned activities, including the supervision of work of assistants when appropriate; ability to pursue and supervise research; strong commitment to both undergraduate and graduate teaching. Assistant Professor: Ph.D. degree engineering, computer science, or equivalent; demonstrated ability to teach; demonstrated scholarly achievement; ability to pursue and supervise research; strong commitment to both undergraduate and graduate teaching. Minimum Academic Salary; Associate Professor: $64,872; Assistant Professor: $51,264. Position is contingent upon the availability of funds. Send resume and three references by August 31, 1993 to Professor Shu Lin, Chairman, Department of Electrical Engineering, University of Hawaii at Manoa, 2540 Dole Street, Holmes Hall 483, Honolulu, HI 96822. An Equal Opportunity/Affirmative Action Employer.

SMU: The Department of Electrical Engineering invites applications for a full-time, tenure-track faculty position at the junior or senior level. The successful candidate should have an earned Ph.D in electrical engineering, demonstrated research ability, with a strong interest and commitment to undergraduate and graduate teaching. Areas of interest include VLSI design, microprocessors, digital systems, telecommunications and related areas. It is anticipated that the position will be filled January, 1994. SMU is a private university with approximately 8,000 students. The Electrical Engineering Department resides within the School of Engineering and Applied Science where a close working relationship exists with the Departments of Computer Science and Engineering and Mechanical Engineering. The EE department presents a balanced program of research and education at all levels and has extensive contacts with engineering oriented industrial firms that distinguish Dallas as one of the top centers of high technology. Please send a complete resume that includes teaching interests, research activities, and the names of five references to: Professor Jerome K. Butler, Chairman, Department of Electrical Engineering, Southern Methodist University, Dallas, TX 75275-0335. SMU is an equal opportunity/ affirmative action, Title IX employer and specifically encourages applications from women and minorities. Applications will be accepted until the position is filled.

Arecibo Observatory, Electronics Department Head. The National Astronomy and Ionosphere Center, headquartered at Cornell University, invites applications for the position of Head of the Electronics Department at the Arecibo Observatory in Puerto Rico. The Observatory, which carries out basic research in radio and radar astronomy and in studies of the earth's atmosphere, is operated by Cornell University for the National Science Foundation. Most of the Observatory's research activities center around the use of the 100-ft. diameter antenna, which is equipped with sensitive receiving equipment for radio astronomical observations at frequencies between 25 MHz and 5 HGz. Two high-powered transmitters at a separate transmitter facility are used for ionospheric modification experiments. A major NSF/NASA-supported upgrading of the 1000 ft. telescope is currently underway, which will make very substantial improvements in its sensitivity and frequency coverage. New analogue and digital instrumentation is under development or planned to support these new capabilities. The Department Head will be responsible for supervising approximately six engineers and twelve technicians and support personnel, interacting with NAIC's research and professional staff to define priorities for instrumentation development, organization of the design and construction of instrumentation, and ensuring that all existing equipment is properly maintained. Applicants should have a BS degree in Engineering, preferably a MSEE, MENG, or PhD, and at least ten years experience in several of the engineering areas of interest to the Observatory: low-noise cooled amplifiers, IF/LO systems, digital signal processors, high-powered transmitters, etc. Experience in managing projects and small engineering groups is highly desirable. The successful candidate will be an employee of Cornell University and eligible for all the University's normal benefits, including health benefits, generous vacation time, and assistance with moving expenses to and from Puerto Rico for non-residents of Puerto Rico. Applications should be received by August 15, although late applications may be considered. Please reply to: Dr. Paul F. Goldsmith, Director, NAIC, 502 Space Sciences Building, Cornell University, Ithaca, NY 14853-6801. Cornell University is an equal opportunity/affirmative action employer.

Athens Technical Institute, Athens, GA, seeks nine-month faculty member in ABET-accredited engineering technology program. Master's degree in electrical engineering or electrical engineering technology, recent industrial experience with programmable logic controllers and microcomputer programming/interfacing, and demonstrated ability to communicate effectively in English required. Consideration given to BSEE or BSEET and master's degree in closely related field. Teaching experience is desirable. Application deadline is Aug. 13, 1993, with employment beginning Fall. Send resume, three letters of recommendation and official transcripts to Dr. Robert A. Hawley, Dean, Athens Technical Institute, U.S. Highway 29 N, Athens, GA 30610. An EEO Institution.

Government/Industry Positions Open

Senior Electrical Engineer. Design power systems for both industrial and commercial projects. Supervise designers and CAD operators. Must have BSEE, professional registration in any state, at least five years design experience, and computer proficiency. Although most assignments relate to power, a knowledge of instrumentation would be beneficial. Typical clients of our firm include municipal water districts, petroleum refineries, copper smelters, and school districts. Bath & Associates, Inc., 4110 Rio Bravo, Suite 102, El Paso, Texas 79902.

Software Engineer III to develop synthesis software for PLD & FPGA devices; modify & support MIS & ESPRESSO synthesis tools; module testing and design improvements. Must have: Master's Degree in Electrical and Computer Engineering w/specialization in FPGA Mapping Techniques; 4 years experience as design/software engineer including digital circuit design, advanced synthesis algorithms (logic synthesis, RTL level synthesis, state machine synthesis) & random logic/boolean minimization. Experience or education must also include work w/CAE tools, C/C++ coding, and SUN UNIX & DOS operating systems. Salary $45,870/year; 40 hrs/wk in Redmond, WA. Send resume by August 1, 1993 to: Employment Security Dept., E&T Div., Job Order #356666, P.O. Box 9046; Olympia, WA 98507-9046. EOE.

Software Design Engineer; By July 31, 1993; Please send resume to: Employment Security Department, E&T Division, Job # 364307-M, P.O. Box 9046, Olympia, WA 98507-9046. Job Description: Designs complex software for microcomputer software under limited supervision. Coordinates program development, writes functional specifications and standards, and performs functional verification of multiuser relational database software product that accommodates localization, including database programming languages. Works with documentation team to ensure accuracy and clarity of documentation and with product support team to ensure availability of technical support for product. Utilizes MS-DOS and Unix operating systems, and BASIC, "C", Xbase, and SQL programming languages. Requirements: Bachelor's degree in Electrical Engineering, Computer Science, Mathematics or Physics; 2 years experience designing and implementing multiuser relational database management systems and applications for systems with personal and mini computers, including database engine and indexed sequential access method software. Must include 6 months work or school thesis project experience in programming or computer software design utilizing MS-DOS and Unix operating systems, "C", BASIC, dBASE and SQL programming languages, design and implementation of a programming language and software localization. 20 course hours in mathematics and database theory. Experience may be gained concurrently. Must have legal authority to work in the United States. Job location: Seattle Area Employer. Salary: $46,000-$52,000 per annum, depending on experience. Compensation package includes bonuses and stock options. 40 hours per week, flex time. EOE.

Telecom Field Engineer to work on satellite systems in remote areas of former Soviet Union. Field experience on VSATs, radios and microwave necessary. Will work with international technical team. Preference to person with inventive attitude. Please fax resume to Vice President, 212-755-0864.

Mgr., new business development, for a manufac. of broad-band and satellite-based comm. networks and instrumentation for telecomm. Detailed technical knowledge of the functionality, architecture and applications of DS3 (45 MB/S) and Sonet test instrumentation and systems required. Will produce business cases for new products, provide market research, interface with customers, conduct technical analysis of competitor's products, interact with R&D and manufac. engineers, provide proposals and quotations (RFI, RFP, RFQ) for new products. Position will submit written reports to senior mgt., monitor new technologies (ATM and SMDS), participate in technical seminars/discussions with carriers, and develop strategic business initiatives including feasibility studies on new product opportunities and will explore relationships with other companies. May supervise aspects of advertising and promotion. B.S.E.E., or equivalent, 7+ years in similar position or as a Sr. Tech Marktg & Sales Engineer required. $63,750/yr. Apply to: Georgia D.O.L. Job Order #GA5615472, 1535 Atkinson Rd., Lawrenceville, GA 30243.

Sr. Consultant. Provide direct coaching, quality assurance & project mgmt. support for Co's proprietary Productivity Plus (P+) methodology. Provide direct support to project teams during all phases of development cycle, from preliminary analysis through to final implementation. Responsible for customizing Co's P+ methodology for evolutionary prototypes. BSCS, Mathematics or related field & 5 yrs. exp. in job offered or 5 yrs. exp. in data & database admin., functional design or project mgmt., in a large info. processing environ. Exp. must inc. hands-on-work with s/w development life cycle methodologies as well as data & process modelling techniques; use of CASE tools; & implementation of current state-of-the-art info. sys. & technologies. Exp. in Productivity Plus also req. $50,000-$60,000/Yr. Job Site/Int.: Seattle, WA. Applicants send ad with resume to Employment Security Dept., E&T Division, Job #364601, PO Box 9046, Olympia, WA 98507-9046 no later than 7-30-93.

Software Design Engineer; By July 31, 1993; Please send resume to: Employment Security Department, E&T Division, Job # 364264-S, P.O. Box 9046, Olympia, WA 98507-9046. Job Description: Designs, implements and tests software for micro computers following standard procedures. Works with other engineers to design and implement an intelligent information linking, search, and access system for a distributed, multitasking operating system. Utilizes formal methods of design to ensure correctness of implementation. Requirements: Master's degree in Electrical Engineering, Computer Science, Mathematics or Physics; 6 months work or minimum of semester long school thesis project experience in programming or computer software design utilizing a multitasking operating system, and design and implementation of software utilizing artificial intelligence search techniques. Experience may be gained concurrently. 20 course hours in formal methods of design and analysis. 20 course hours in artificial intelligence and distributed computing. Must have legal

authority to work in the United States. Job location: Seattle Area Employer. Salary: $40,500-$42,500 per annum, depending on experience. Compensation package includes bonuses and stock options. 40 hours per week, flex time. EOE.

Network Systems Analyst/Programmer. Will serve in network analyst capacity including plan, design, and integration of leading edge network technologies and also be responsible for day-to-day operation and network management of production state-of-the-art Unix LAN and WAN. Working in a heterogeneous environment, the analyst will be responsible for integrating various high speed network peripherals and distributing computing components found in the high performance computing platforms at the Center. In addition, the person will be required to evaluate current and future network and telecommunications based technology and actively contribute to the long term computing and networking strategy of the Center. Candidate will be responsible for implementation and management of portions of distributed computing services including distributed file systems, security software, RPC, NTP, and threads. Knowledge of DCE, ATM, HIPPI and FDDI networking in a UNIX environment. Education and Experience: BS/BA degree in Computer Science, Engineering or equivalent experience. Master's Degree preferred. Extensive experience in the area of high speed networking and telecommunications including design and management of a large scale Unix-based heterogeneous network is essential. Both configuration and programming based experience of TCP/IP network protocols is required. Experience working with distributed systems, including distributed computing systems, distributed filesystems and data management systems. The North Carolina Supercomputing Center (NCSC), a division of MCNC, is a state-supported Supercomputing Center and Research Institute located in the Research Triangle Park, North Carolina. Send resume to MCNC, PO Box 12889, Research Triangle Park, NC 27709-2889, reference position 4M6. We are an equal opportunity employer.

Engineer, Control Systems. Specify, evaluate and commission instrumentation and control systems for refineries and petrochemical plants; specify & configure distributed control systems (DCS) and programmable logic controllers (PLC); specify analyzers, hydrocarbon detectors, vibration monitors and field instruments. Size orifice plates and control valves. Develop piping and instrument diagrams (P&ID's) and logic diagrams using ISA standards. Implement advanced controls for distillation columns, compressors and furnaces. Req's MSEE or MS in process monitoring and control. Min. 3 yrs. exp. in job offered or in instrumentation engineering experience for refinery or chemical plants. Exp. must include: DCS and PLC configuration; implementation of advanced controls; and utilization of on-line analyzers, hydrocarbon detectors, vibration monitors, control valves and flow meters. Job site/interview, Houston. $4,100/mo. Apply at the Texas Employment Commission, Houston, Texas, or send resume to the Texas Employment Commission, TEC Building, Austin, Texas 78778, J.O. #TX6844357. Ad paid by an Equal Opportunity Employer.

Megacell Design Engineer III. Develop silicon compilers (C/UNIX) in ChipCrafter environment for customer-specified designs using Compiler Development System, SPICE circuit simulator, schematic editor & Verilog simulator; provide analog/digital circuit design, layout & verification for standard & custom megacells; develop algorithms for Digital Signal Processing (DSP) esp. for full motion video data compression; verify algorithms through computer simulation & translate from concept to silicon in ChipCrafter/EPOCH design environment; develop new ideas for megacell/chip design, focusing on telecommunications & DSP. Must have: Master's Degree in Electrical Engineering inclu. 18 credit hours in VLSI Circuit Design, Layout, Simulation & Testing, 3 credit hrs in Communication Theory & 3 credit hrs in Signal Processing; 1 year work exper w/ C programming under UNIX, plus or concurrently, 1 year work exper in Analog/Digital/Mixed Signal VLSI design & testing using ChipCrafter or EPOCH. $41,000/yr; 40 hrs/wk in Bellevue, WA. Send resume by July 30, 1993 to: Employment Security Dept., E & T Div., Job Order #369314, PO Box 9046, Olympia, WA 98507-9046.

Megacell Design Engineer V to design & develop Epoch Megacell Library focusing on digital signal processing, control, communications, consumer product related chips & other ASICs. Also responsible for assisting CAD tool groups w/ design, development & maintenance of VLSI CAD tools. Must have: Ph.D. in Electrical Engineering inclu. 20 grad. credit hours in circuits & electronics and 16 grad. credit hours in system theory, 1 1/2 years research exper. in system design process inclu. algorithm development, system, register & gate level simulation, detailed VLSI implementation. Exper. must have included work w/ ChipCrafter & Verilog and design of floating point units & instruction set processors. Salary $52,000/year, 40 hrs/wk in Bellevue, WA. Send resume by July 30, 1993 to: Job Order #370560, Employment Security Dept., E & T Div., PO Box 9046, Olympia, WA 98507-9046.

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Scanning
The Institute

Globalization committee seeks bigger world presence

Several ways of increasing world membership are being considered by the IEEE's *ad hoc* committee for the globalization of the Institute. A more flexible membership structure might be one way to attract more members, with extra categories being aded to the present seven, according to the committee chair, President-Elect H. Troy Nagle. Added options might include, for example, groups devoted to the practical aspects of design and applications (for example, for digital design, analog circuits, and manufacturing).

Another possibility is novel kinds of networks to help members get in contact with each other. As an example, Nagle cited the relatively new consultant networks being set up in several IEEE Sections. He suggested that other networks could be patterned after that model or that different models might be developed. A subcommittee on membership options, chaired by James Tien, has been set up to examine this approach.

Some of the globalization committee's other activities will be to:

- See that fewer members leave (like students and recent graduates).
- Enter into partnerships with national electrical engineering societies.
- Improve industry's support of and participation in the IEEE.
- Emphasize the IEEE's role in the international electrotechnology community.

PEER II job search abandoned

IEEE–United States Activities (IEEE-USA) has had to abandon one of its efforts in the job placement business. Instead, it will direct members to local IEEE and commercial employment agencies.

A year-long contract with Success Systems Inc., Torrance, CA, to run the Professional Engineering Employment Registry II (PEER II) was not renewed when it expired. The main factor in the decision was members' dissatisfaction with the service, according to John E. Martin, chairman of IEEE-USA's Employment Assistance Committee.

Not just a résumé referral service, the registry was to give a job seeker diskettes of job openings culled from companies, placement services, and periodicals on the basis of such factors as his or her location preferences, areas of expertise, and length of experience.

The problem, according to one IEEE staff member, was that "there's not a whole lot of jobs out there for engineers," so that people with 25 years of experience would receive listings for entry-level jobs. "I'm sorry it didn't work," said Martin. "It sounded so great."

He pointed out that members can avail themselves of local IEEE job referral services in Boston; Long Island, NY; Cleveland, OH; and San Diego, Long Beach, and Orange Country, CA. Members may obtain a list of existing commercial registries (some of them are free), participate in IEEE-cosponsored job fairs and workshops, and obtain IEEE-USA videotapes and books. Contact IEEE-USA for more details by calling 202-785-0017.

AAES honor awarded to Herz

Eric Herz (F), director emeritus of the IEEE, received the Kenneth Andrew Roe Award from the American Association of Engineering Societies. The award recognizes an engineer who has been effective in promoting unity among the engineering societies of the nation and the world. Herz received an honorarium of US $3500 as well as a framed citation.

Coming
in Spectrum

BUSINESS NO LONGER AS USUAL. The massive layoffs at high-technology multinational corporations herald permanent changes in business globally and are not just a belt-tightening response to cyclical hard times. For example, lifetime employment may be giving way to the engineering free lance, says this special report.

LOSSLESS DATA COMPRESSION. Squeezing the redundancy out of a file with a compression algorithm makes the data less costly to transmit. The applications for lossless compression are varied, as are the mathematical approaches that may be used.

COMPUTER VIRUSES, II. The spread of future computer viruses will be favored by greater machine speed and interoperability—and possibly countered by automatic threat characterization and statistical "kill signals." This is the second part of a two-part article.

THE NEED FOR OTHERS' KNOW-HOW. The competitive gathering of industrial intelligence, long a Japanese forte, will be key to corporate success in the '90s, argues the author—a Japanese.

CHIP PROTECTION SUCCESS. In the first successful case brought under the 1984 act protecting IC layouts, Brooktree Corp. won huge damages against American Micro Devices Inc., which was found to have infringed three Brooktree IC patents.

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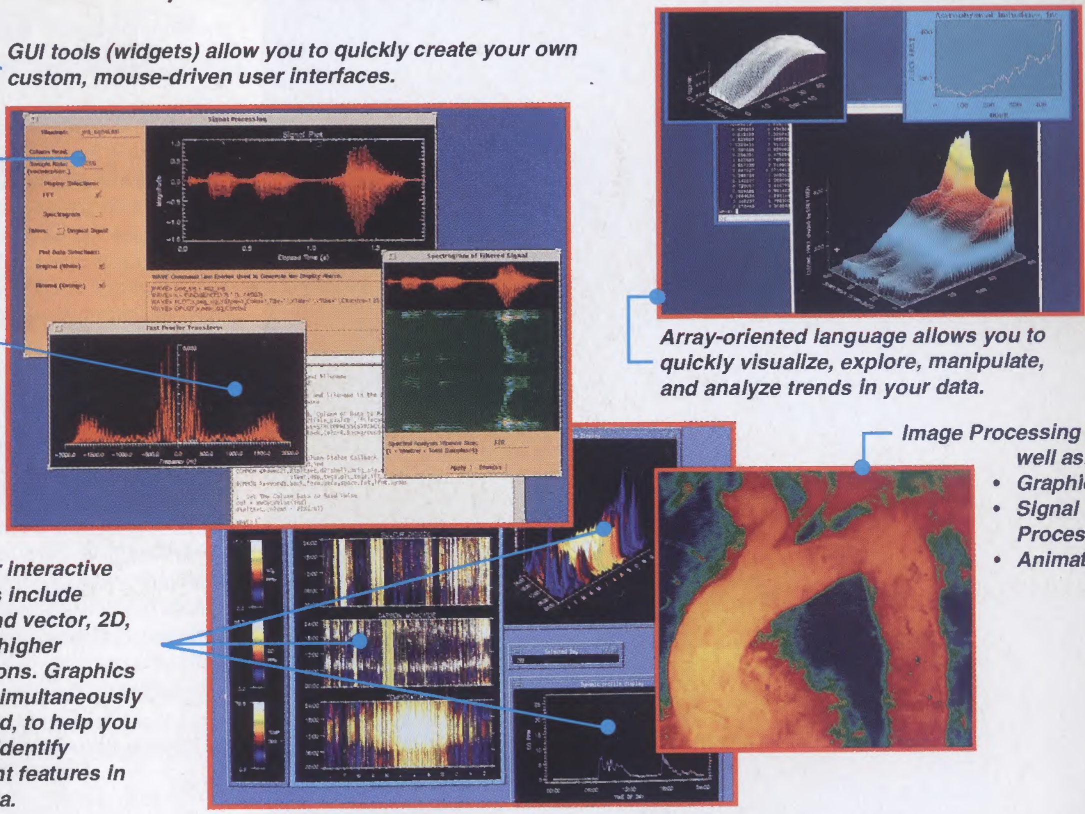

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